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VOL. 35. No. 5 MAY 2006

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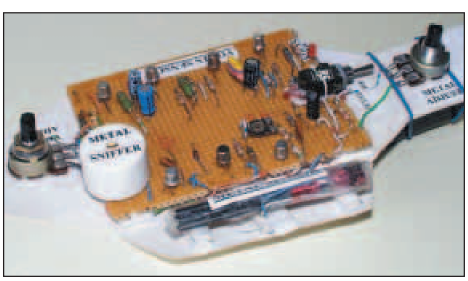

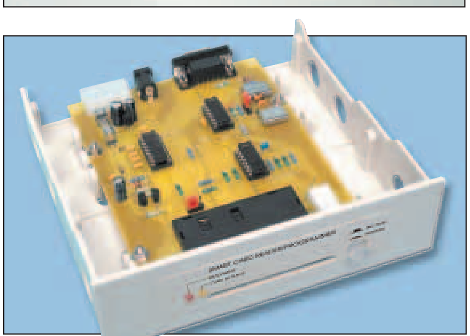

Our June 2006 issue will be published on Thursday, 11 May 2006. See page 80 for details

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EVERYDAY PRACTICAL ELECTRONICS

THE UK's No.1 MAGAZINE FOR ELECTRONICS TECHNOLOGY & COMPUTER PROJECTS

VOL. 35 No. 5 **MAY 2006**

Editorial Offices:
EVERYDAY PRACTICAL ELECTRONICS EDITORIAL
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Phone: (01202) 873872. Fax: (01202) 874562.
Email: enquiries@epemag.wimborne.co.uk
Web Site: www.epemag.co.uk
EPE Online (downloadable version of *EPE*)**:** www.epemag.com
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PCBs

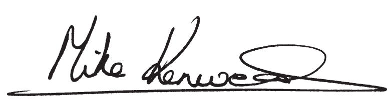
In line with the new directives our PCBs are now being supplied with lead-free solder tinning, readers will also have noticed that some PCB masters are no longer being carried in all articles. Sometimes this is due to the size of the PCB but more often to save space in the article. What we have done is to place the PCB masters on our website so they can be downloaded and printed off, which should actually make them easier to use than the masters in the magazine.

Many constructors simply buy PCBs from our *EPE PCB Service* but there are some constructors who have the ability to make their own boards and who enjoy doing so. We certainly do not want to prevent those that want to from making their own PCBs. So if you need a PCB master pleased go to the "Downloads" section of our UK website (**www.epemag.co.uk**) and click on the PCB Masters file. You will then find recent boards listed by their reference numbers e.g. 567 for the *Smart Card Reader/Programmer* in this issue.

Lead Free

The whole subject of lead free soldering seems to be worrying some readers. We covered this in our feature *Coping With Lead-Free Solder* in the May '04 issue and found that, with the correct "tools", there should be little problem for the average constructor. However, as our contributor Bill Mooney said at the end of the article "like every other aspect of electronics the art of soldering will get more complex and cannot be taken for granted."

We have put this article in the Library section of our Online issue so it can be downloaded free of charge (**www.epemag.com**). Incidentally, the Library section includes a number of free articles and Supplements plus adverts from the latest issue which can be accessed by anyone and downloaded "instantly" free of charge. Take a look, there is much of interest there.



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Subscriptions for delivery direct to any address in the UK: 6 months £17.50, 12 months £33, two years £61; Overseas: 6 months £20.50 standard air service or £29.50 express airmail, 12 months £39 standard air service or £57 express airmail, 24 months £73 standard air service or £109 express airmail. To subscribe from the **USA** or **Canada** see page 70.

Online subscriptions, for downloading the magazine via the Internet, $15.99US (approx £9.50) for one year available from **www.epemag.com**.

Cheques or bank drafts (in **£ sterling only**) payable to *Everyday Practical Electronics* and sent to EPE Subs. Dept., Wimborne Publishing Ltd. 408 Wimborne Road East, Ferndown, Dorset BH22 9ND. Tel: 01202 873872. Fax: 01202 874562. **Email:** subs@epemag.wimborne.co.uk. Also via the **Web** at: **http://www.epemag.wimborne.co.uk**. Subscriptions start with the next available issue. We accept MasterCard, Amex, Diners Club, Maestro or Visa. (For past issues see the *Back Issues* page.)

BINDERS

Binders to hold one volume (12 issues) are available from the above address. These are finished in blue p.v.c., printed with the magazine logo in gold on the spine. Price £7.95 plus £3.50 p&p (for overseas readers the postage is £6.00 to everywhere except Australia and Papua New Guinea which cost £10.50). *Normally sent within seven days but please allow 28 days for delivery – more for overseas.*

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READERS' TECHNICAL ENQUIRIES

E-mail: techdept@epemag.wimborne.co.uk
We are unable to offer any advice on the use, purchase, repair or modification of commercial equipment or the incorporation or modification of designs published in the magazine. We regret that we cannot provide data or answer queries on articles or projects that are more than five years old. Letters requiring a personal reply *must* be accompanied by a **stamped self-addressed envelope or a self-addressed envelope and international reply coupons. We are not able to answer technical queries on the phone.**

PROJECTS AND CIRCUITS

All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it.

A number of projects and circuits published in *EPE* employ voltages than can be lethal. **You should not build, test, modify or renovate any item of mains powered equipment unless you fully understand the safety aspects involved and you use an RCD adaptor.**

COMPONENT SUPPLIES

We do not supply electronic components or kits for building the projects featured, these can be supplied by advertisers.

We advise readers to check that all parts are still available before commencing any project in a back-dated issue.

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The Publishers regret that under no circumstances will the magazine accept liability for non-receipt of goods ordered, or for late delivery, or for faults in manufacture.

TRANSMITTERS/BUGS/TELEPHONE EQUIPMENT

We advise readers that certain items of radio transmitting and telephone equipment which may be advertised in our pages cannot be legally used in the UK. Readers should check the law before buying any transmitting or telephone equipment as a fine, confiscation of equipment and/or imprisonment can result from illegal use or ownership. The laws vary from country to country; readers should check local laws.

News . . .

A roundup of the latest Everyday News from the world of electronics

LOCATION-FREE TV

Sony has announced its next generation of view-anywhere TV systems

Barry Fox reports

Sony missed the boat when Apple launched iPod and iTunes, was late getting into large screen LCD, and lost valuable years backing plasma. At recent briefings in Tokyo the company showed how it has learned from past mistakes, learned some humility and got the creative juices flowing again. New boss Sir Howard Stringer has restructured to "revitalise the core business of electronics" with tight focus on two areas, Mobile and Home. Stringer is now committed to cutting the number of product models by 20% from 30,000, and losing 10,000 people.

The new system, called Locationfree TV, uses a broadband base station to stream video from a Freeview box, satellite receiver, DVD player or hard disc recorder onto the Internet, for remote access. At a Tokyo WiFi cafe we saw UK TV channels on a laptop, and even changed channels with the click of a mouse cursor.

Says Satoru Maeda, General Manager of Sony's Video Business group: "Our target is a location-free world. In the future there will be Locationfree HDTV. We have been working on the concept for several years and have many patents. We are now licensing the technology to other companies and providing Software Development Kits. Ten companies in the US, Europe and Japan have taken licenses".

Bit rate can be set to any of six settings, or more easily set to Auto. "We recommend around 500kbps for the best quality", says Maeda who had just flown back from Korea watching Japanese TV on a Boeing plane with onboard WiFi. "It was using about 150kbps on the plane. At that speed you cannot watch 30fps but if necessary you can watch at 5fps".

WiFi Enabled Games

Locationfree also works with PSP portable games consoles, which are all WiFi-enabled. The PSP automatically downloads the necessary software when the owner uses the Network Update option. PSP already has the necessary MPEG-4 playback capability so from then on the Locationfree Player option appears on the PSP menu.

At around 300kbps in the Tokyo WiFi cafe the pictures from DTTV in Europe looked excellent on PSP, very good at around half screen size on a laptop and acceptable in full screen mode. Channel switching was surprisingly fast, taking not much longer than local switching. 128-bit encryption ensures privacy.

Locationfree base stations and PC software are already on sale in Japan and the European PAL launch will follow in the summer when Sony has collected all the IR codes needed for remote control of Freeview tuners. British children will then be able to watch CBBC while on holiday in the USA, using a PSP.

Students should be able to watch their parents' Sky Sports from college digs. Or do you prefer the idea of watching last night's TV on your pocket PSP while on the train to work next day? Sony's RDR-AX75 costs $700 and records broadcast TV to a 250GB hard disc in two different ways at the same time; in high quality for conventional big screen TV playback using the standard MPG-2 system and also in the lower quality MPEG-4 standard which is tailored to PSP's smaller screen. Data rates are either 384kbps or 768kbps, QVGA standard.

Rapid Copying

Because the lower quality recording uses much less digital code, it can be copied by standard USB cable to the PSP's Memory Stick at high speed. A one hour TV recording takes only two minutes to transfer to the PSP before leaving for work.

"A 2GB Memory Stick can store two movies", says Hodaka Irikuchi, Business Manager for Home Video Marketing. Irikuchi also demonstrated a new system called x-Pict Story. "Usually when you take digital pictures and transfer them to a PC, they die in the PC", he said. x-Pict Story is software built into a standalone DVD recorder with hard drive and Memory Stick slot.

When you put in a Stick with snapshot pictures, the hard drive builds a slide show with fades, mixes, pans and zooms – like rostrum photography. It also adds background mood music, all completely automatically, taking only a minute or so. The show can then be burned to DVD to give to friends. The feature is already built into three recorders, the RDZ-D90, D70 and D50 for $1300, $1000 and $800.

Sony has now all but given up on plasma. All new TVs are LCD. Says Kei Sakaguchi, General Manager of Corporate PR: "We made mistakes. We lagged on LCD. We bet on plasma but LCD developed faster than expected. Our choice of technology was wrong. So we entered into a joint venture with Samsung".

Sideways Viewing

The first fruits of the joint venture are now showing. Super Patterned Vertical Alignment solves the main problem with LCDs; if you view from the side, the colours look washed out – bright reds turn to pastels. All screens use a large glass sheet coated with a million or more individual cells of liquid crystal material, covered by transparent electrodes. When current is fed to the electrodes it alters the alignment of the liquid crystal molecules and this controls how much light can be shone through the cells from a backlight. Red, green and blue filters over the cells add colour.

In conventional LCDs the cells are switched off to block light and make a black part of the picture, on to pass light, and part way between on and off to make grey. When a viewer sits directly in front of the screen, viewing head-on, the picture colours look natural. But when the screen is viewed from the side the relative balance between the red, green and blue greys changes with the angle of viewing. So the overall picture colour changes as the viewer moves sideways.

Smaller Cells

The new screens divide all the LCD cells into several smaller parts, each of which can be separately switched on or off. To make black, all parts of a cell are switched off; to make a bright colour all are on and for grey some are on and some are off – in the same way that the density of black and white dots of a newspaper picture create the illusion of greys. The effect is the same regardless of whether the screen is viewed from the front or side. So colour balance is stable over 178 degrees.

Kei Sakaguchi also acknowledges what critics have said about the MagicGate Digital Rights Management software that encumbers Sony's MP3 players: "We lagged behind on the user interface. We honoured copy protection very heavily. But usability was not so good." In a pragmatic move Sony has created a new concept to cater for lost customers who replaced their cassette Sony Walkmen with Apple iPods. Cradle Audio is a docking station, the size and shape of a Toblerone bar of chocolate that houses a digital amplifier and two tiny speakers. A separate power unit also acts as a sub-woofer. The cradle docks with a Sony Ericsson phone or connects with an iPod by analogue line socket cable. It also streams music round the house by WiFi.

A 600 watt version of the amplifier module is used in the SCD-DR1 SACD/CD player and TAD-DR1A amplifier, that cost a cool £12,000.

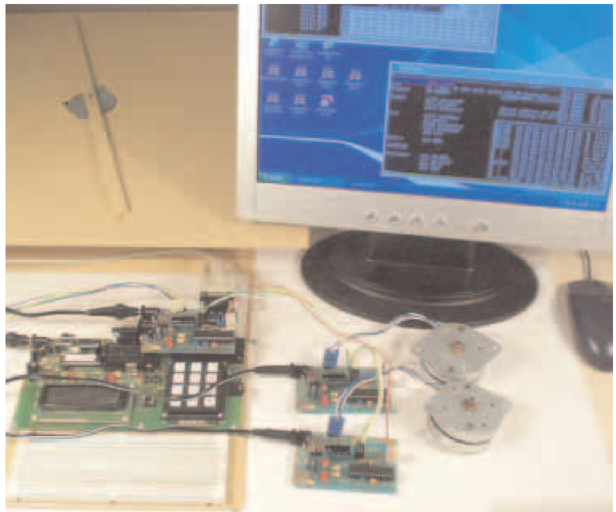
BRUNNING PIC18F SOFTWARE

Brunning Software have announced the release of an extension to their PIC training and development system. Inspired by the latest wave of 18F PICs, Peter Brunning has sifted through the complications. His latest book *Experimenting with 18F PICs*, with software written in PIC assembler, shows that with the right approach 18F PICs can be easier to use than 16F PICs. He starts by flashing LEDs, writing text to the LCD, using a keypad, experimenting with serial data, experimenting with speed control of DC motors, and finally studies simple and accelerated control of stepper motors. The new book is sold with software on CD, a stepper motor controller module and a stepper motor.

The stepper motor controller has eight high current MOSFETs arranged as two bridge outputs. Each bridge circuit will run continuously at 1A and handle transients of 18A.

The book, software on CD, stepper motor controller with RS232 input/output, one stepper motor and one PIC18F2525 are sold together. Total price £81.90

For more information contact Brunning Software. Dept EPE, 138 The Street, Little Clacton, Clacton-on-Sea, Essex CO16 9LS, Tel: 01255 862308. Web: **www.brunningsoftware.co.uk**



E-blocks 2006 Cat

Matrix Multimedia, whose excellent range of tutorial CD-ROMs we sell through *EPE* (see elsewhere in this issue), have sent a catalogue of E-blocks products. E-blocks are small circuit boards each of which contains a block of electronics that you would typically find in an electronic system.

John Dobson, Managing Director of Matrix Multimedia, comments that "the E-blocks range has grown so much in the last couple of years that we have decided to give it a whole brochure of its own for 2006". In its pages you will find details of the 40 hardware E-blocks boards, CDs, sensors, training solutions, and numerous accessories that currently make up the range.

It's a well-presented brochure and worthy of your closer attention.

For more information contact Matrix Multimedia, Dept EPE, The Factory, Emscote Street South, Halifax, West Yorks HX1 3AN. Tel: 0870 700 1831. Fax: 0870 700 1832. Email: sales@matrixmultimedia.co.uk. Web: **www.matrixmultimedia.co.uk**.

1Km FM RC SYSTEMS

R.F. Solutions have introduced a new series of long-range, handheld FM remote control systems. The new 434MHz systems are able to achieve an impressive line-of-sight range of up to 1000 metres. There is a choice of single, twin or four channels, and suitability for use with either 12V/24V DC or 230V AC makes them suitable for a wide range of applications.

Supplied as a transmitter and decoder pair, the systems use the Microchip Keeloq protocol to ensure highly secure and reliable operations. Installation is quick and easy with power supply and relay output connections made by screw terminals. A useful "easy learn" feature enables the decoder to quickly learn up to 50 unique transmitters. This data is retained even after power-down.

For more information contact R.F. Solutions, Dept EPE, Unit 21, Cliffe Industrial Estate, South Street, Lewes, East Sussex BN8 6JL. Tel: 01273 488880. Fax: 01273 480661. Web: **www.rfsolutions.co.uk**. Email: sales@rfsolutions.co.uk.

Easier Slave Speakers

Fitting a pair of extension speakers in the kitchen or bathroom, with the option to remote-control the music system in the living room, just got a whole lot easier – and safer. A new system, called Incognito from British hi-fi company Cambridge Audio, plays clever tricks to work with simple wiring and no need for extra mains power. By using wires instead of WiFi it reliably reaches through walls.

New Cambridge Audio hi-fi equipment will now have an extra "Incognito" socket on the rear. This socket looks like the standard Ethernet RJ-45 socket on a PC, and it connects to standard 8-core Cat-5 Ethernet cable. But instead of connecting to a PC network or Internet broadband, the Cat-5 cable runs to a pair of Incognito in-ceiling speakers which work like slaves to the main living room amplifier.

The slave speakers are "active", with a built-in slave amplifier that is powered by 24V DC fed down the Cat-5 cable from the main living room amplifier. The cables also carry line level analogue audio down to the slave speakers from the main amplifier and CD player. So the slave speakers need no mains power and are safe to use in a humid bathroom.

The slave speakers also have a built-in infra red sensor for receiving control signals from a handheld remote. The sensor then sends electrical control codes up the Cat-5 cable to the living room amplifier, to control volume. The living room amplifier and CD player also have matching miniature jack sockets which let a simple jack jump lead feed control signals from the Cat-5 cable and living room amplifier into the CD player. So a handheld remote control in the bathroom or kitchen can also play, pause and skip CD tracks.

The main amplifier has two identical RJ-45 sockets so that it can feed the same entertainment to two sets of slaves in two separate rooms, in addition to the main room. More elaborate versions of the Incognito system use a control hub to allow more complex switching of independent audio and video signals in different rooms. But these systems will usually require installation by a skilled engineer. The basic Incognito system can be installed by any DIY enthusiast who feels comfortable laying a length of Cat-5 cable and installing a pair of speakers in a ceiling or a cavity wall.

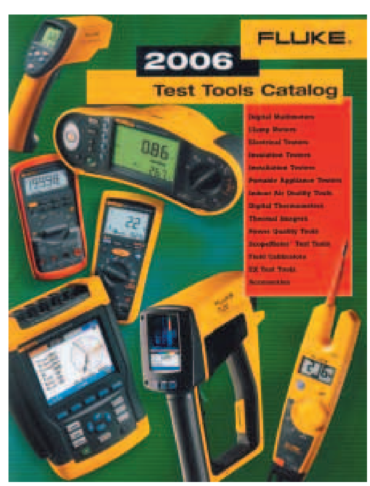
The Azur 640A amplifier with Incognito connections costs £300, the matching 640C CD player is £250 and a pair of AS10 active slave speakers adds £270.

Barry Fox

FLUKE TOOLS CAT

Fluke has just released its free 2006 Test Tools catalogue. It has more sections and new products than ever before. The 92-page full-colour book is packed with information that goes beyond mere product data. It provides hints and tips about picking the right test tools for specific needs, and includes applications and background articles, such as safety advice, basic electrical testing and trouble shooting. The new section on ATEX-certified tools looks at intrinsically safe test tools.

For your copy or further information contact Fluke on 0207 942 0700 or via **www.fluke.co.uk**. Fluke's UK branch is at Fluke (UK) Ltd, Dept EPE, 52 Hurricane Way, Norwich, Norfolk NR6 6JB



Test your reaction times with a DIGITAL REACTION TIMER

BY JIM ROWE

So you think your reaction time is pretty good. Well, you might be surprised. This little project will let you test your own or anyone's reaction time and read it out accurately on a digital multimeter. The 'Brake!' stimulus is a large red LED, while the subject's response can be sensed via a pushbutton, footpedal switch or even an optical detector, set up to sense the light from a car's brake lamp.

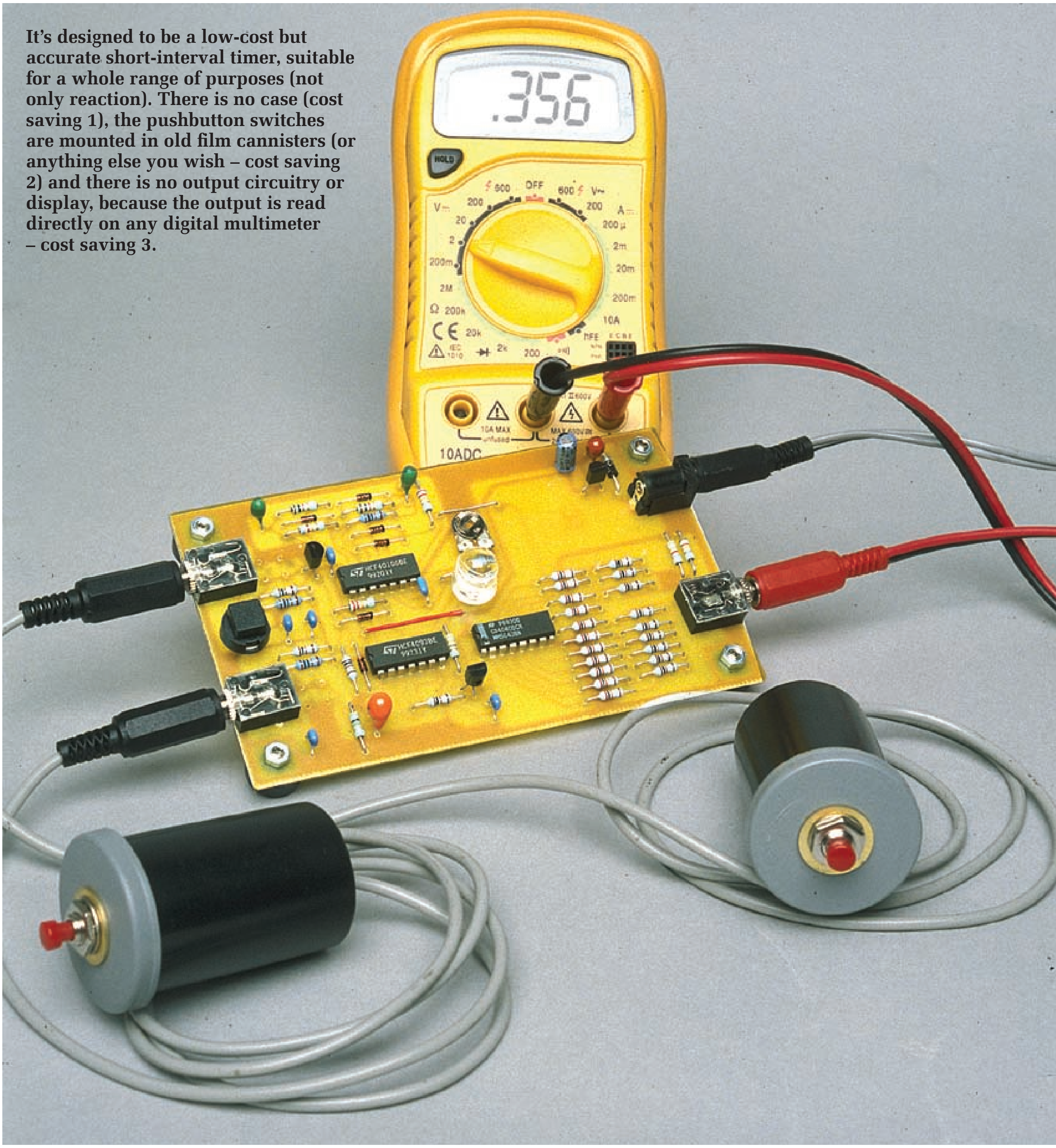
EVERYONE TAKES a finite time to respond to any stimulus, whether it's the brake lamp from the vehicle in front at 70mph on the motorway, touching a hot saucepan on the stove or whatever.

There's the short time for the nerve impulses from your senses to travel to your brain, the time for your brain to respond and then a further short time for outgoing nerve impulses to travel to your limbs and stimulate the muscles to produce your reaction.

These three delays are usually lumped together into a single quantity known as your reaction time: the total time taken for you to actually respond to such a stimulus.

Your reaction time varies depending on whether you respond with your hand or your foot. It also depends on your state of health, alertness, psychological outlook and whether you have recently taken drugs or alcohol.

The reaction time for a normal healthy adult seems to vary from 150 to 300ms (milliseconds) for a hand response and from 400 to 800ms for a foot response (eg, hitting the brakes). If you are driving a vehicle and your measured reaction times are significantly longer than these times, you are an "accident waiting to happen".



It's designed to be a low-cost but accurate short-interval timer, suitable for a whole range of purposes (not only reaction). There is no case (cost saving 1), the pushbutton switches are mounted in old film cannisters (or anything else you wish – cost saving 2) and there is no output circuitry or display, because the output is read directly on any digital multimeter – cost saving 3.

You don't need to be a rocket scientist to work out why. Consider driving at 70mph. At that speed, you're travelling over 100ft every second or almost 10ft (approx. 3m) each 100ms. So if it takes you (say) 500ms to respond to an emergency by stepping on the brake pedal, your car will travel almost 50ft (approx. 15m) before the brakes can even begin to slow you down.

Some safety experts have suggested that reaction time testing should be mandatory for driver's licence renewals. It hasn't happened yet – but in the meantime you can measure the reaction time of all your driving friends, to judge whether they should be on the road or not . . .

Uses a digital multimeter

This Reaction Timer uses a digital multimeter (DMM) to read out the time in milliseconds; you just switch it to the 2V DC range.

The unit runs from a 9V battery or DC plugpack. It measures the time you take to press the Stop button (or a foot switch) after the "Brake" LED is lit and converts that time into a DC voltage (1ms = 1mV). So your digital multimeter can read reaction times directly. A reading of say 335mV

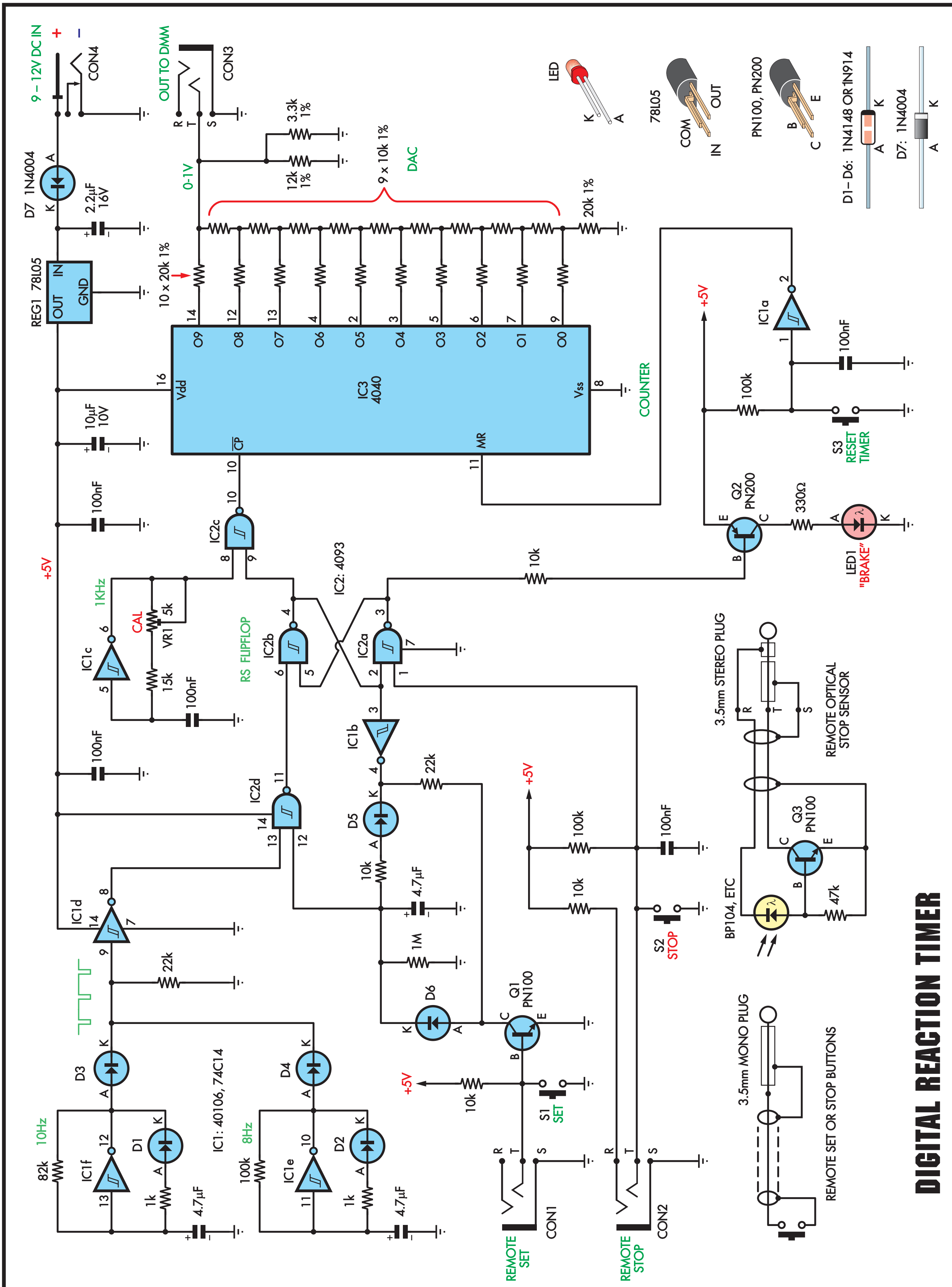

DIGITAL REACTION TIMER
9 – 12V DC IN
CON4
OUT TO DMM
CON3
D7 1N4004
2.2µF 16V
REG1 78L05
OUT
GND
IN
0-1V
3.3k 1%
12k 1%
9 x 10k 1%
DAC
10 x 20k 1%
20k 1%
IC3 4040
COUNTER
Vdd
Vss
CP
MR
10µF 10V
100nF
+5V
IC2c
IC2: 4093
1KHz
CAL
VR1
5k
15k
IC1c
RS FLIPFLOP
IC2b
IC2a
IC1b
IC2d
IC1d
22k
D5
D6
10k
4.7µF
1M
Q1 PN100
S1 SET
D3
D4
D1
D2
IC1f
IC1e
10Hz
8Hz
82k
100k
1k
IC1: 40106, 74C14
REMOTE SET
CON1
REMOTE STOP
CON2
S2 STOP
100k
100nF
Q2 PN200
330Ω
LED1 "BRAKE"
S3 RESET TIMER
IC1a
3.5mm STEREO PLUG
REMOTE OPTICAL STOP SENSOR
Q3 PN100
BP104, ETC
47k
3.5mm MONO PLUG
REMOTE SET OR STOP BUTTONS
LED
78L05
COM
IN
OUT
PN100, PN200
D1 – D6: 1N4148 OR 1N914
D7: 1N4004

Fig.1 (left): the circuit uses a 1kHz clock pulse generator based on IC1c. Its pulses are gated through to binary counter IC3 (via IC2c) during the time that the "Brake" LED (LED 1) is illuminated. The counter outputs are then fed to a ladder DAC to produce an analogue voltage for the DMM.

corresponds to a reaction time of 335ms, and so on.

Using a DMM for the readout keeps the circuit simple and the cost low. It also keeps the current drain low as well, so the tester will operate for quite a long time from a standard 9V battery. The current drain is only 4mA when the LED is not lit, rising to 14mA when the LED is on.

Can you jump the gun?

Nope. But you can have fun trying! To make it impossible to 'jump the gun' – even when you're measuring your own reaction time – there's a built-in variable time delay before the 'Brake!' LED is lit, after the Set button is pressed.

So even if you press the Set button yourself, or notice when the operator presses the button, there's no way of guessing when the LED will light. It could be anything from a fraction of a second up to a few seconds, before the LED lights and your reaction time begins to be measured.

You are, therefore, forced to concentrate on the LED, and then push the Stop button as soon as you see it light up.

The measuring range of the timer is from zero to 1023ms, or just over one second. If your reaction time is longer than this, the timer's output voltage drops back to zero and starts again. This is hardly a problem though, because if your reaction time is longer than 1023ms you should be a passenger, not a driver!

How it works

The full circuit diagram for the Digital Reaction Timer is shown in Fig.1. At the heart of the timer is a simple clock-pulse generator (IC1c) producing a string of pulses at a rate of one pulse per millisecond (ie, 1kHz).

These clock pulses are controlled by a logic gate (IC2c), which is opened only during the time that the 'Brake!' LED is illuminated. Pulses from the gate are then fed to a binary counter (IC3) which counts how many pulses have been allowed through the gate.

We then use a simple digital-to-analogue converter (DAC) to convert the count into a DC output voltage, ready for measuring by a DMM.

That's the basic idea. Now we can look at the circuit of Fig.1 in more detail.

The 1kHz clock pulses are produced by the circuitry around IC1c, one section of a 40106 or 74C14 hex Schmitt trigger inverter. This is connected as a relaxation oscillator, with the 5kΩ variable resistor VR1 used to adjust its oscillation rate to exactly 1kHz.

The pulses from IC1c are fed to gate IC2c, the main timing gate. IC2c is one section of a 4093 quad Schmitt NAND gate. The pulses which IC2c allows through are fed to the clock input of IC3, which is a 4040 12-stage binary counter. We only use 10 of the 12 outputs, as this allows us to count up to 1023 (one less than the 10th power of 2).

Ladder DAC

The 10 outputs of IC3 are in binary form, each one swinging between 0V and 5V as the counting proceeds. The combination of 10 binary outputs is converted into an equivalent analogue DC voltage by the DAC 'ladder network' of 10kΩ and 20kΩ resistors.

This simple but effective DAC ensures that each output is given the correct 'binary weighting' at the output. That is, the effect of each counter output halves with its position down the ladder. Output O8 produces half the output voltage of O9, O7 produces half that output again and so on.

As this basic DAC produces an output voltage varying from 0V to just on 5V, we use the two additional 12kΩ and 3·3kΩ resistors connected from the DMM output to earth to form the lower half of a voltage divider. This reduces the output voltage range to 0 to 1·023V, ensuring that the DMM will read directly in millivolts.

So IC1c, IC2c, IC3 and the resistor ladder network are essentially the core of the timer, able to count a time period and convert it into an equivalent DC voltage.

Reaction Times

Now let's see how we make this timer measure reaction times. Gate IC2c is controlled by an RS flipflop formed from gates IC2a and IC2b (4093). When this flipflop is in the Set state with IC2b pin 4 high, gate IC2c is 'open' and allows 1kHz pulses through to the counter.

If you mount the pushbutton switches in a film cannister or similar, it's a good idea to fit a large flat washer to stop the switch being forced through the plastic due to over-exuberance!

At the same time transistor Q2 is turned on by the logic low at the output of IC2a (pin 3), via the transistor's 10kΩ base resistor. This turns on the 'Brake!' LED. This LED remains alight while the timer is actually measuring a reaction time, ie, until the person being tested pushes the STOP button S2.

When the person being tested presses the Stop button (either S2, or a remote switch via CON2), this pulls pin 1 of IC2a low, which switches the RS flipflop back to its reset state. The output of IC2b goes low, turning off gate IC2c to stop the counter, while the output of IC2a goes high at the same time which turns off Q2 to extinguish the LED.

But what switches the flipflop into the set state in the first place, to start the timer and light the LED? Now that's a little more tricky – which is why we've left it until last.

Random start delay

The flipflop is switched into the set state by applying a brief logic low pulse to pin 6 of IC2b; we could do this by connecting the Set button S1 (or a remote switch via CON1) to this pin via a simple RC debounce circuit like that used for the Stop button S2. But this would turn on the LED and timer immediately, leaving the timer susceptible to errors caused by a subject "jumping the gun".

As a result, we've introduced a variable delay between pressing S1 and the actual turn-on of the flipflop, which

Parts List

1 PC board, code 569 (available from the *EPE PCB Service*), 76 x 128mm
1 momentary contact pushbutton switch (S3)
2 momentary contact pushbutton switches (S1, S2) OR
2 3·5mm PC-mount stereo jacks (CON1,2)
1 3·5mm PC-mount stereo jack (CON3)
1 2·5mm concentric power socket (CON4)
4 rubber feet, screw mounting type
4 M3 x 6mm machine screws with M3 nuts
1 3·5mm mono jack plug
1 1-metre length of light-duty figure-8 cable
2 banana plugs (one red, one black)
2 3·5mm mono jack plugs (optional)
2 2·5m lengths of shielded audio cable (optional)
2 pushbutton or foot switches (optional)
1 5kΩ horizontal trimpot (VR1)

Semiconductors
1 40106 or 74C14 hex Schmitt trigger (IC1)
1 4093 quad Schmitt NAND gate (IC2)
1 4040 12-stage binary counter (IC3)
1 78L05 3-terminal regulator (REG1)
1 PN100 NPN transistor (Q1)
1 PN200 PNP transistor (Q2)
1 10mm bright red LED (LED1)
6 1N4148 diodes (D1-D6)
1 1N4004 power diode (D7)

Capacitors
1 10µF tantalum, 10V
3 4·7µF tantalum, 10V
1 2·2µF tantalum, 10V
5 100nF monolithic (code 100n or 104)

Resistors (0·25W 1%)

1 1MΩ	1 12kΩ
3 100kΩ	13 10kΩ
1 82kΩ	1 3·3kΩ
2 22kΩ	2 1kΩ
11 20kΩ	1 330Ω
1 15kΩ	

"randomises" the turn-on procedure. This works as follows. Schmitt inverters IC1f and IC1e are both connected as relaxation oscillators, similar to the clock oscillator (IC1c) but with both working at much lower frequencies. IC1f runs at about 10Hz while IC1e runs at around 8Hz, determined mainly by the 4·7µF capacitors and the 82kΩ or 100kΩ resistors.

Both these oscillators produce an output in the form of very narrow negative-going pulses. This is due to the effect of the 1kΩ resistors and diodes D1 or D2 which make the 4·7µF capacitors discharge very rapidly on every half-cycle. So both outputs are at the logic high level for about 99% of the time and only at logic low level for about 1% of the time. In other words, the oscillators have a very high duty cycle or mark-space ratio.

Because the two oscillators are running at different frequencies, these narrow negative-going pulses coincide only occasionally. So by combining them in the AND gate formed by diodes D3, D4 and the 22kΩ resistor, we end up with a voltage across the resistor which is at logic high level most of the time, only occasionally going low very briefly. This becomes our source of pseudo-random pulses for triggering the flipflop.

The occasional low pulses are inverted by IC1d and then fed to one input of NAND gate IC2d, which controls when they are allowed through to pin 6 of IC2b. The remaining circuitry using Q1, diodes D5 & D6 and inverter IC1b is used to ensure that the flipflop is switched to the set state on the arrival of the first 'random' pulse from IC1d after the Set switch S1 has been pressed.

They also ensure that the flipflop can't be retriggered again for some time, so that it switches to the reset state as soon as the Stop button is pressed, and remains in that state. This works as follows.

While the flipflop is in the reset state, the output of inverter IC1b is high. This means that the 4·7µF capacitor connected between pin 12 of IC2d and 0V could potentially charge up to logic high via D6 and the 22kΩ resistor, except for the fact that transistor Q1 is switched on by the 10kΩ resistor connected to its base.

But if the Set button S1 is pressed, Q1 turns off and the 4·7µF capacitor charges up rapidly, bringing pin 12 of IC2d to logic high level. IC2d then turns on, allowing the next 'random' pulse from IC1d to pass through to the flipflop and switch it to the Set state.

Resistor Colour Codes

❑	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	1	1MΩ	brown black green brown	brown black black yellow brown
❑	3	100kΩ	brown black yellow brown	brown black black orange brown
❑	1	82kΩ	grey red orange brown	grey red black red brown
❑	2	22kΩ	red red orange brown	red red black red brown
❑	11	20kΩ	red black orange brown	red black black red brown
❑	1	15kΩ	brown green orange brown	brown green black red brown
❑	1	12kΩ	brown red orange brown	brown red black red brown
❑	13	10kΩ	brown black orange brown	brown black black red brown
❑	1	3·3kΩ	orange orange red brown	orange orange black brown brown
❑	2	1kΩ	brown black red brown	brown black black brown brown
❑	1	330Ω	orange orange brown brown	orange orange black black brown

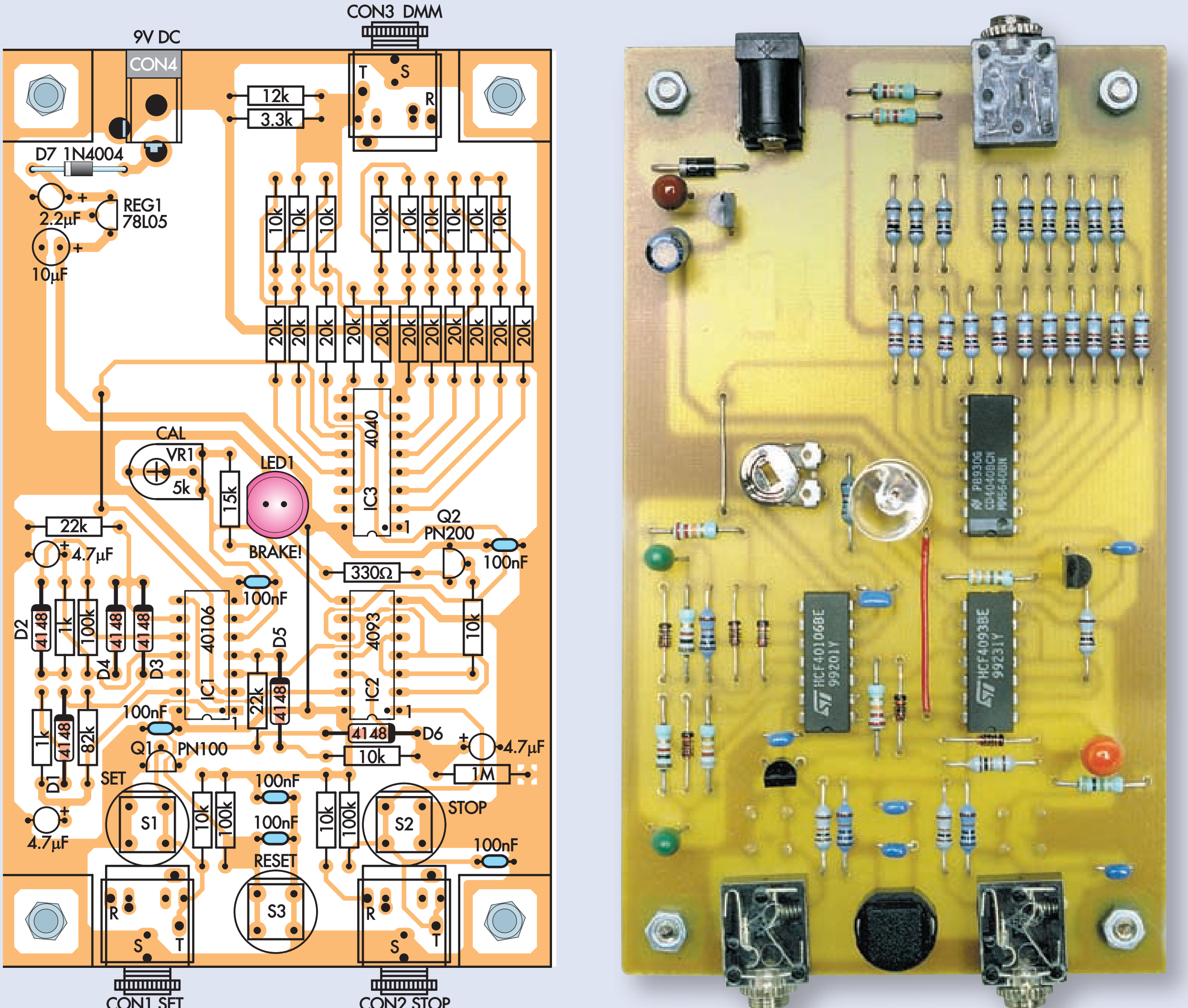


Fig.2: full-size component overlay, along with matching photograph at right. Between these two you should have no problems with construction

Because of the high value of the 1MΩ resistor connected in parallel with the 4·7µF capacitor, the capacitor takes about 10 seconds to discharge when S1 is released. This means that you only have to press S1 briefly and the circuit remains 'primed' and ready to let through the next trigger pulse from IC1d, even if this doesn't arrive for a few seconds.

But how do we prevent the triggering circuit from being able to turn on the flipflop a second time, after the Stop button S2 has been pressed?

That's the purpose of D5 and its series 10kΩ resistor, because they ensure that any charge on the 4·7µF capacitor is rapidly drained away as soon as the flipflop is switched on. When the flipflop switches to the Set state, the output of IC1b goes low, D5 conducts and the capacitor discharges through the 10kΩ resistor in less than 100ms.

Reset function

When the timer's flipflop is switched off by the Stop button (S2), counter IC3 simply stops counting with its outputs remaining at the millisecond count that was reached. This means also that the timer's DC output remains fixed, giving you as much time as you need to read the DMM and record the time reading.

Reset switch S3 resets the counter to zero so you can perform another reaction time measurement. Associated with switch S3 is a 100kΩ resistor and a 100nF capacitor which form a 'de-bounce filter'. This is followed by inverter IC1a which provides a positive-going reset signal for IC3 when the button is pressed.

As well as being a de-bounce filter, the 100kΩ resistor and 100nF capacitor also form a 'power-on reset' circuit to reset IC3 as soon as power is connected to the circuit.

Power for the circuit can come from a 9V battery or 9V DC plugpack. This is fed through diode D7 to prevent reversed-polarity damage and is then passed through 5V regulator REG1.

Trigger options

You have two options regarding the timer's Set triggering. The simpler approach is to use on-board push-button S1 but this means that the person being tested will be well aware when you have 'started the ball rolling'.

The alternative approach is to fit socket CON1 instead of S1 and

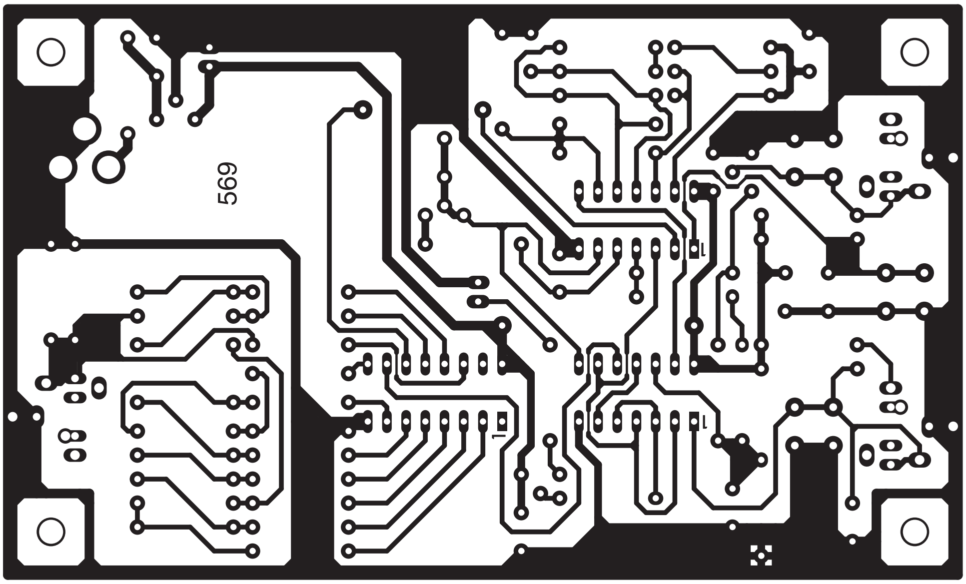


Fig.3: this is the full-size pattern for the single-sided PC board used in this project.

connect to it a remote pushbutton (or foot switch) via a length of shielded cable and a suitable plug. The remote pushbutton can be mounted in a film container or some other small case that can be handheld.

This allows you to press the Set button out of the test subject's sight (although, as we've said before, there is a random time period after this switch is pushed to prevent cheating!).

The same two approaches are available for the Stop triggering, where you can again use either on-board pushbutton S2 or a remote pushbutton connected via CON2.

In this case there's also a third option; instead of connecting a simple pushbutton via CON2, you can connect a small optical sensor circuit, so the timer can be stopped by an optical signal of some kind; eg, the stop lamp of your car.

In this way, you could simulate an actual braking situation (without the risk of a collision!).

As shown on the circuit diagram, the optical sensor can consist of a BP104 or similar photodiode, a 47kΩ resistor and a PN100 transistor.

Putting it together

Virtually all of the timer's circuitry fits on a small PC board measuring 76 × 128mm and coded 569 (available from the *EPE PCB Service*). The component overlay diagram is shown in Fig.2.

The only off-board wiring consists of the cables running to your DMM and to a 9V battery or plugpack supply, plus those to the remote Set and Stop buttons if you elect to use them.

The PC board assembly is intended to be used 'as is', supported by four small rubber feet.

Before starting assembly, inspect the copper side of the PC board carefully and make sure there are no hairline cracks in the copper tracks, or solder or copper bridges shorting them together. Fix any defects.

Then start by fitting the two wire links to the top of the board. One of these is just to the left of trimpot VR1, while the other is just to the left of IC2 and IC3. This second link should be made from a short length of insulated hookup wire.

Next, fit the various connector sockets to the board: DC power socket CON4, DMM output socket CON3 and the optional sockets CON1 and CON2 for the remote Set and Stop buttons. Note that the PC board has holes and pads to match either type of commonly available board-mounting 3·5mm stereo jack sockets, so there shouldn't be any problems.

If you're not fitting CON1 and CON2, you can fit pushbutton switches S1 and S2 instead, plus the Reset button S3, which goes at the front centre of the board. Note that S3 must be fitted with its 'flat' side towards the back of the board. This also applies to S1 and S2, if you fit them.

Next you can fit trimpot VR1; you may also need to slightly enlarge the PC board holes before the pins will pass through easily. The board has holes to allow either common type of mini trimpot to be fitted.

The resistors can be fitted next, using the colour codes in the parts list as a guide. If you're not confident about reading the colour codes, use your DMM to check the resistor values. It's also a good idea to fit the resistors with their colour codes reading in the same directions, to make checking and troubleshooting easier in the future.

With the resistors fitted, you can fit the remaining low-profile parts: signal diodes D1-D6 (all 1N4148 or 1N914) and the polarity protection diode D7 (a 1N4004). Take special care to fit all of these diodes the correct way around, as shown in the diagram of Fig.2.

If you don't, the timer either won't work at all, or you're likely to get some very strange results.

Once the diodes are soldered in place you can fit the small monolithic capacitors, and then the tantalum capacitors.

Don't forget that the tantalum capacitors are polarised, and must be fitted into the board with the correct polarity. You should find each one's polarity clearly marked on its body, and the positive side is indicated on the overlay diagram to guide you.

All that remains is to fit transistors Q1 and Q2, voltage regulator REG1, the 10mm LED and the three ICs. The main things to watch here are that you make sure to fit each one in its correct location and with the correct orientation as shown in the overlay diagram of Fig.2.

REG1 is in the same type of TO-92 package as Q1 and Q2, so don't confuse them. Note that some 10mm LEDs don't have a 'flat' moulded into their plastic pack, so the only easy way to check their polarity is by the longer length of their anode lead. Therefore, make sure you fit LED1 to the board with this longer lead on the side nearest IC3.

We suggest that you solder the LED's leads to the board pads with the bottom of the LED package only about 8-9mm above the board. This allows you to bend both leads forward by about 30°, so that the LED is tilted towards the front.

Because all three ICs are of the CMOS type, it's a good idea to take precautions to prevent them from being damaged by static electricity while you're handling

and fitting them. The best way to do this is by making sure that the PC board's copper tracks, your soldering iron and yourself are all at earth potential for this part of the operation.

To earth yourself, you can use a conductive wrist strap, connected to an earthed water pipe via a length of flexible insulated wire. This also allows you to drain away any charge on the board copper by simply touching it before you fit the ICs.

Once the ICs are fitted, the final step in the board assembly is to fit the board with small rubber mounting feet, using four M3 x 6mm machine screws and M3 nuts.

You also need to make up a lead to run from the timer to your DMM. This should have a 3·5mm jack plug on one end and a pair of banana plugs at the other. If you use red/black colour coded cable for this lead and fit red and black banana plugs, this will make it easy to connect up to the DMM with the correct polarity every time.

Mind you, most DMMs these days have auto polarity, so it's not really a problem.

If you're using remote Set and Stop switches, you'll also need to make up the remote switch leads. These can use single-core shielded wire for the plain pushbutton or footswitch leads, fitted with mono 3·5mm jack plugs. You only need to use shielded stereo cable and a stereo jack plug for the optical Stop sensor, because the extra wire and jack connection are needed for the photodiode bias voltage.

Checkout and Calibration

Your reaction timer should now be complete and ready for checkout and calibration. The first step is to connect it to a 9V battery or nominal 9V DC plugpack. Use your DMM to check the voltage at pin 14 of either IC1 or IC2, or pin 16 of IC3 (measured against board earth, such as the lefthand end of the two resistors between CON3 and CON4). You should read +5V at all three of these IC pins.

The LED should not be lit but if you briefly press Set button S1, the LED should light soon afterwards – within a few seconds. If 10 seconds pass and the LED still hasn't begun glowing, try pressing S1 again briefly. This should cause the LED to light within another few seconds. If not, you've probably made a wiring error. So remove the 9V supply and look for a reversed diode or transistor.

Once the LED does light, try pressing Stop button S2. This should extinguish the LED immediately. If you have connected the timer's output lead to your DMM, it should now indicate a steady DC voltage somewhere between 0V and 1·023V. If you then press the Reset button S3, the voltage should drop back to zero.

Assuming the above checks are successful, your Reaction Timer is working correctly and all that remains is to calibrate it so that your reaction time readings will be accurate. This can be done quite easily, although you do need access to either a calibrated oscilloscope or a frequency counter. These days, many of the better DMMs incorporate a frequency meter.

If you don't have access to either of these instruments, you might have to simply set trimpot VR1 to the centre of its adjustment range and hope for the best.

If you do have access to a calibrated 'scope or frequency counter, accurate calibration is easy. All you have to do is connect the (high impedance) input of either instrument to either pin 6 of IC1 or pin 8 of IC2 and read the frequency of the square-wave signal. Then adjust VR1 until the frequency reads as close as possible to 1kHz (1000Hz).

That's it. With the clock pulse rate set to 1kHz, the timer's output voltage should be within 2% or better of the reaction time period in milliseconds.

Camera shutter timer?

While we haven't tried it we imagine that this circuit (especially the main timing oscillator, counter and DAC) would also be quite useful as a short interval timer – eg, for checking camera shutter speeds. Obviously the "random start" oscillators (IC1e, IC1f) would not be needed, nor would the "Brake" LED or its associated circuitry.

One way to sense the "lens open" time would be to use a phototransistor or photodiode to sense light coming through the lens. Again, we must emphasise that we haven't tried this but we would imagine the phototransistor could be used to simply control IC2c, which in turn would allow oscillator pulses from IC1c into the counter on "light" and stop them on "dark". ***EPE***

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EXTREME ELECTRONICS

Do you respect risk takers and admire people who take their passions to the edge? Some folk will go all the way in electronics and take their hobby to the ultimate, as Mark Nelson discovers

DO you remember the book *101 Uses For A Dead Cat*? I do, or at least I remember the title, as I never read or saw the book itself. But that's the phrase that came to mind when I read recently a truly novel application for a microwave oven. So why can't we have a book or website called *101 Uses For A Redundant Microwave Oven*?

Mysterious Lights

In fact someone has beaten me to this idea but I'll come back to that later. However, there was nothing funny or stupid about the news report that I read and in fact it may take us closer to unravelling a scientific mystery that has perplexed enquiring minds for decades, if not centuries. The subject is "ball lightning", a phenomenon in which spheres of light appear to hover in the air or move with great rapidity before vanishing just as suddenly as they appeared.

Some atmospheric lights are known as "will-o-the-wisps" and are said to be self-combusting marsh gas, a clearly chemical phenomenon. Others, known as "earth lights", are seemingly electromagnetic and take on glowing, polymorphous forms, the result of seismic pressures associated with the constantly rising and falling tectonic stress in the Earth's crust creating plasma electricity above the ground. All these apparitions are observed only by night.

Ball lightning, on the other hand, appears in full daylight and is genuinely spherical, glowing orange and looking like luminous ping-pong balls or melons, although some reports mention objects the size of beach balls or larger and having different colours. Some witnesses speak of an acrid smell and a fizzing sound, whilst my own observation was silent and odourless.

Experts claim these phenomena are closely associated with regular lightning and thunderstorms and that was certainly my own experience some fifty years ago. Following an incredibly loud thunderclap directly outside, a glowing ball of light shot out of our large valve radio and disappeared in seconds, leaving the radio undamaged. Do write in if you too have witnessed ball lightning.

Small Balls of Fire

Expert theory is one thing but live experimentation is quite another, which is why I was delighted to read that scientists in Israel have managed to create ball lightning in the laboratory. The credit for this goes to Eli Jerby and Vladimir Dikhtyar at the University of Tel Aviv in Israel, who harnessed a 600-watt magnetron, removed from a domestic microwave oven, to create a powerful microwave beam for boring through solid objects. The purpose of their experiment was using light to drill through solid objects and their chance discovery came about when they pulled away the drill from the molten object.

In the process some of the superheated material was dragged away from the target, creating a pillar of fire that then morphed into a bright fireball that floated and bounced across the ceiling of the metal enclosure. According to a paper published in the journal *Physical Review Letters*, the glowing object measured about an inch across and looked, according to Jerby, "like a hot jellyfish, quivering and buoyant in the air". It vanished after 10 milliseconds but not before the phenomenon had been caught on video. According to the website *LiveScience*, the composition of the laboratory lightning ball still needs to be verified but appears to resemble those found in nature.

Home Hazard

Something that the laboratory experiment demonstrated very well is the extreme suitability of microwave ovens for superheating things. It also illustrates the strange quirks that superheated materials can display, calling for extreme care and understanding.

Unfortunately, you aren't required to hold a degree in physics to buy a microwave oven, which is why re-heating mugs of coffee in them has landed far too many people in casualty. Heating baby food in a microwave is another absolute no-no.

The technical explanations are far too lengthy to handle here but in a nutshell a microwave oven can heat liquids to a temperature far hotter than normal boiling point, at which point any tiny disturbance (such as you blowing on the surface or tipping in some sugar) can trigger an explosion of violent boiling liquid. Deceptively, the water gets hot but the container usually does not, especially if it's a plastic cup.

Without the "boiling bubbles" of conventional heating methods to cool the coffee, the temperature of the water can easily rise far higher than 100 degrees centigrade to become superheated water, a notoriously unstable substance. Disturbing it creates giant steam bubble "explosions" that can scald you or destroy the container. Not nice at all.

Don't Try This At Home!

There are plenty of other potentially lethal effects you can create in a microwave, many of which are illustrated on websites (see links at end of article).

Steve's Deadly Computer Stuff does at least warn you he is not responsible for your stupidity if you try and emulate his experiments, which include the violent destruction of light bulbs, crisp bags, aluminium foil and discarded cellphones. Less excitingly, he devotes a page to things that do very little when nuked in this way (such as bubble wrap). He also invites other people to share the results of their experiments, although whether this is admirable or deplorable I cannot quite be sure.

The *PowerLabs Microwave Experiments* site demonstrates the production of plasmas and ball lightning with a home oven but also warns you of the dangers of extreme thermal burn. The images are magnificent but you are best advised to watch the pictures and do nothing else. The rest of the site shows some fascinating electromagnetic weapons, a solid-state can crusher, modern-day Wimshurst Machines and much more.

Operation Overkill

This magazine has the word "Practical" in its title, so is there anything useful you can make out of a redundant microwave oven?

Well, yes there is if you are into amateur radio or wireless networking. In fact as long ago as July 1989, American radio ham and inventor David Pacholok, callsign KA9BYI, described an amateur television transmitter he had built from a microwave oven (in *73 Amateur Radio* magazine). This successfully put out over 300 watts of power on the amateur 2·4GHz (13 centimetre) band and the same technique would work equally well for a wi-fi hotspot operating on 2·5GHz.

Probably too well in fact, as it would cover a very wide area and your RF "black hole" problems would be no more than a memory. On the other hand this "Operation Overkill" might well fry every wireless network card in a mile radius as well as attracting the radio investigation service within hours!

LINKS

Superheating and Microwave Ovens (with scary movie)
www.phys.unsw.edu.au/~jw/superheating.html

Steve's Deadly Computer Stuff
http://steve.deadlycomputer.com/microwave/index.html

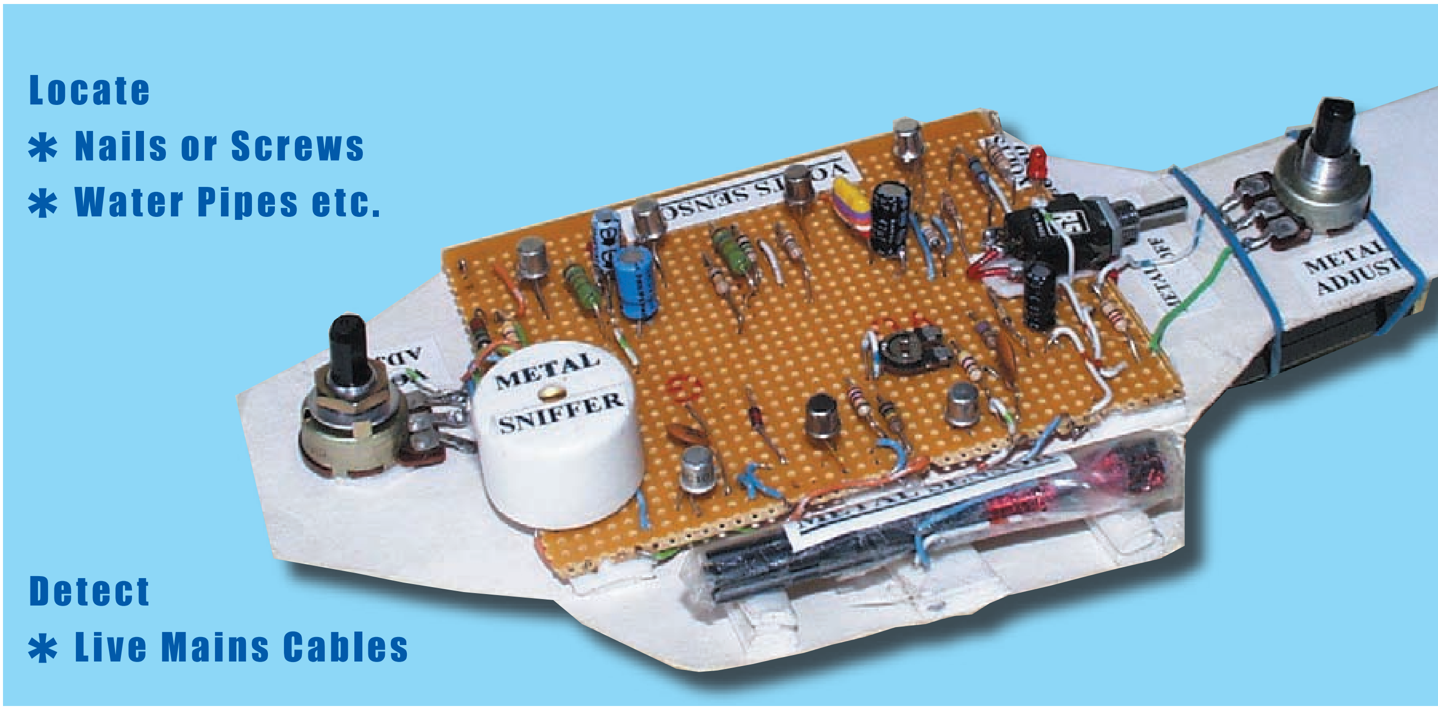
PowerLabs Microwave Experiments
www.powerlabs.org/uwavexp.htm

Funny Things To Do With Your Microwave oven
http://margo.student.utwente.nl/el/microwave/

Hidden Hazards of Microwave Cooking
www.mercola.com/article/microwave/hazards.htm

ATV Transmitter From a Microwave Oven (link from 2304 Tech Page)
http://6mt.com/2304tech.htm

Oven Magnetron as a 13cm TX?
http://lea.hamradio.si/~s57uuu/mischam/magnetr/index.htm



Nail Sniffer & Volts Hound

Two monitors to help you do DIY safely!

By EDWIN CHICKEN MBE MSc

THE Nail Sniffer and Volts Hound are two useful items of hand-held battery-operated equipment for DIY enthusiasts.

The Nail Sniffer locates metal objects such as nails or water-pipes underfloor or within a wall. The Volts Hound indicates the location of hidden live a.c. mains cables. They are easy and cheap to make using readily available components.

Minimalist

The principles of operation for these two types of detector are long established, but in this case the component count has been minimised for economy and component values have been optimised for best performance. Although shown here conjoined as a dual-purpose assembly, each could be made and used separately if so desired.

The finished unit remains unboxed but very usable, simply by fixing with double-sided sticky pads or tape to a piece of shaped cardboard. A single-pole double-throw toggle switch with centre off, selects for use either the Nail Sniffer or the Volts Hound.

History

The need for such detectors arose when the author was preparing to drill through some expensive wall-tiles to instal a bathroom accessory which had to be mechanically secure. The tiles were known to be surface-mounted on a plaster-boarded cavity wall with an inner wooden frame, so the first requirement was to locate the frame to accommodate the fixing screws. That was vital if drilling holes in the wrong place through those posh ceramic tiles was to be avoided.

Further, before beginning drilling, it was necessary to be sure that there were no vulnerable pipes or electric mains cables lurking. In a nut-shell, the required detection circuits were designed and assembled as described here.

Volts Hound

The circuit diagram for the Volts Hound is shown in Fig.1. The design responds to the electric field set up by the voltage on a cable connected to the a.c. mains supply, but not necessarily delivering current. It's worth remembering that an electric field is related to voltage, whereas an electromagnetic field is produced by current flow. So, for instance, when a small metal probe is in the presence of an a.c. electric field, it will also acquire an a.c. voltage, albeit of small magnitude.

In this application, a short length of stripboard copper track is used as the a.c. field sensor. In Fig.1, this is notated as inductor L1. The sensor's low-voltage a.c. output feeds into the relatively high impedance at the base (b) of transistor TR1, which amplifies the signal. From TR1 the signal is a.c. coupled via capacitor C1 to the base of TR2, used as a second amplifier.

The voltage gain of TR2 is adjustable by the sensitivity control VR1. Transistor TR2's output is applied via resistor R6 to the base of TR3, which in conjunction with TR4 and feedback components C3 and R8, forms a voltage-sensitive trigger circuit. The trigger is used to switch on l.e.d. D1 when the sensor detects the presence of a live a.c. mains cable.

Nail Sniffer

The circuit diagram for the Nail Sniffer is shown in Fig.2. It is based around a self-excited LC (inductance/capacitance) oscillator formed around coils L1 and L2, capacitor C5, and transistors TR5 and TR6.

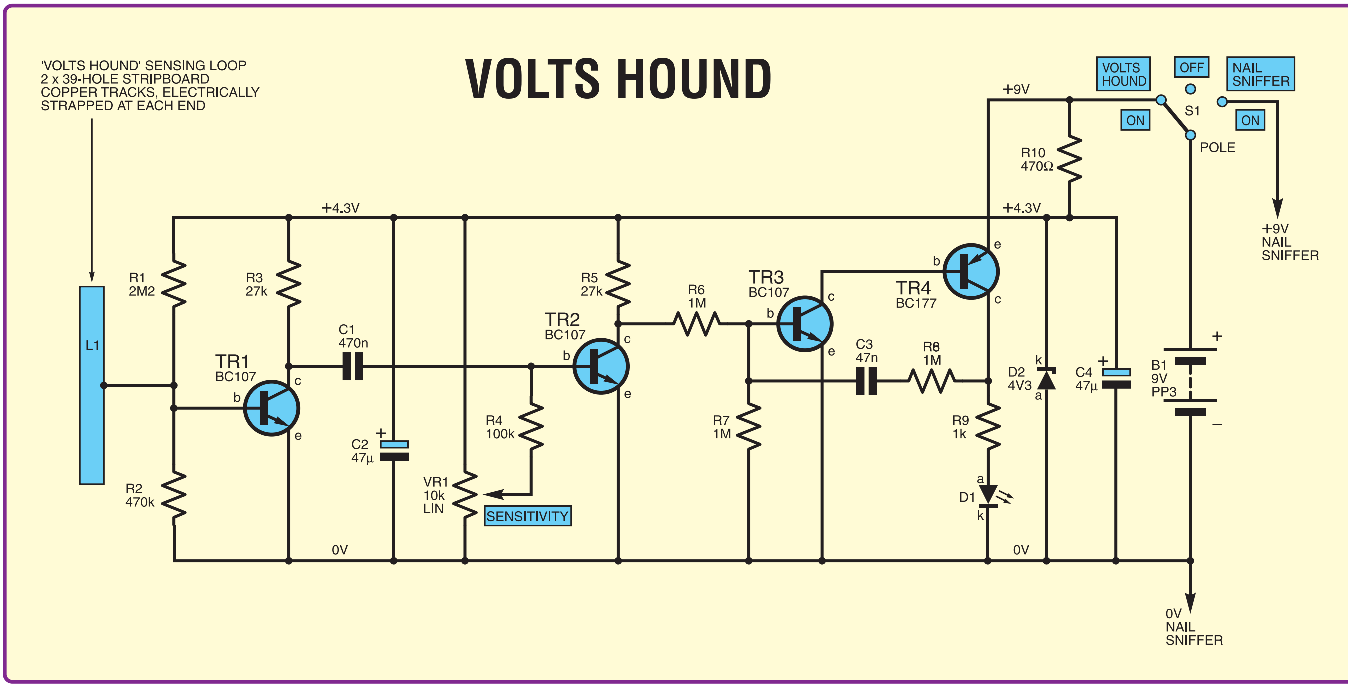


Fig.1. Complete circuit diagram for the Volts Hound section. This circuit can be used as a stand-alone unit or linked to the Nail Sniffer circuit as indicated

Coil L1 and parallel capacitor C5 set the oscillator frequency to be somewhere near the low-frequency end of the Longwave broadcast band at about 130kHz. The output from TR6's collector is fed into TR7, to drive the piezo buzzer WD1 when the oscillator's tuning-coil is brought close to metal.

The amplitude of the oscillatory voltage produced by TR5 is adjusted by potentiometers VR2 and VR3 such that TR6 is just on the brink of being triggered, but not yet actually triggered. In this state, the signal level is incapable of switching on TR7 and the piezo buzzer WD1.

Any metal brought to within a few centimetres of coil L1 will absorb some energy from the electromagnetic field radiated by it. This in turn reduces the magnitude of the oscillatory signal, which causes the trigger stage TR6 to operate, so turning on TR7 and WD1.

Power Supply

Power to the circuits can be supplied by a 9V battery, such as a PP3. Switch S1 selects which circuit is to be switched on.

In both circuits, the 9V supply is reduced down to 4·3V by Zener diodes D2 and D4 respectively. The supply current is limited by resistors R10 and R15, and smoothed by capacitors C4 and C7.

The voltage stabilisation of the two stages remains sensibly constant over the lifetime of the battery.

Construction

Both circuits are constructed on the same piece of stripboard, whose component layout details are shown in Fig.3, together with the details of the breaks required in the underside copper tracks.

Make all the track cuts shown, using a stripboard cutting tool, or a 5mm

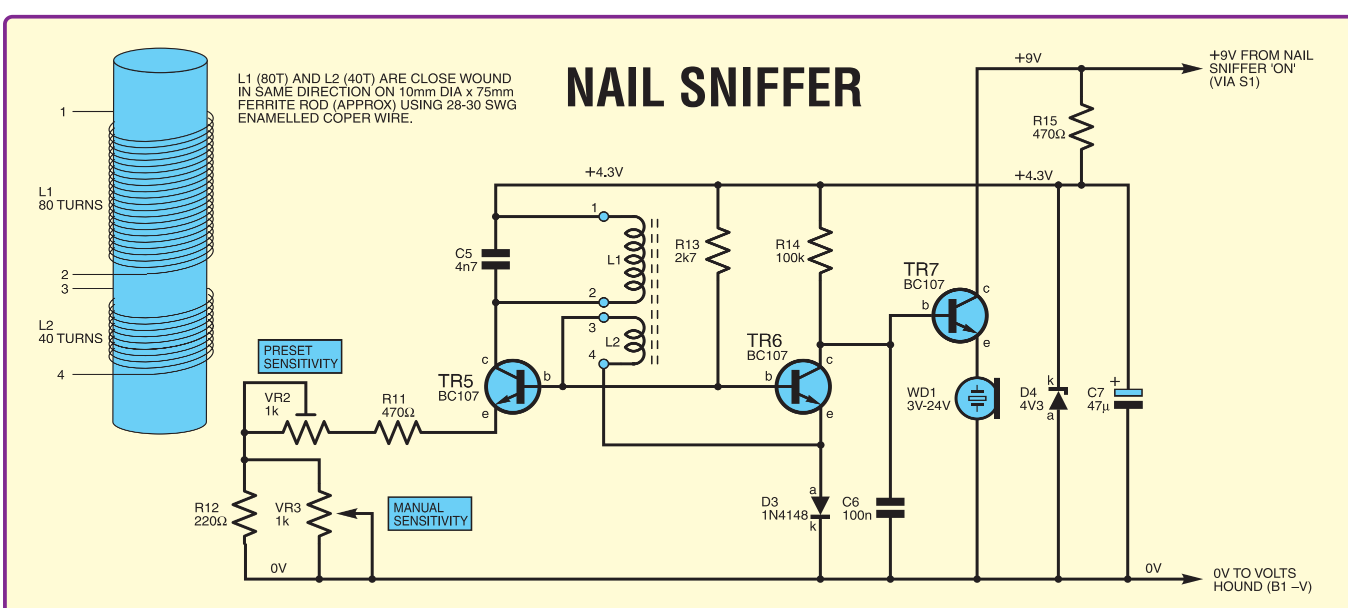


Fig.2. Complete circuit diagram for the Nail Sniffer. This circuit can also be used separately, with its own battery supply

diameter twist drill, and assemble in ascending order of component size. Ensure that all components are inserted correctly, and the right way round where appropriate (all semiconductors and electrolytic capacitors). Double check the completed assembly for poor soldering or "bridged" copper tracks before applying any power to the circuit board. The ferrite rod on which to wind the Nail Sniffer coils L1 and L2 should be available from most electronic component retail sources. Alternatively, the ferrite antenna from any defunct transistor radio receiver can be used, as can the wire.

Coil Winding

The physical length of the ferrite rod is not absolutely critical, neither is the number of turns for L1 or L2, nor is the resultant oscillatory frequency. Before winding the coils, first straighten out about five metres of enamelled copper wire, using a cloth to

NAIL SNIFFER & VOLTS HOUND CIRCUIT BOARD

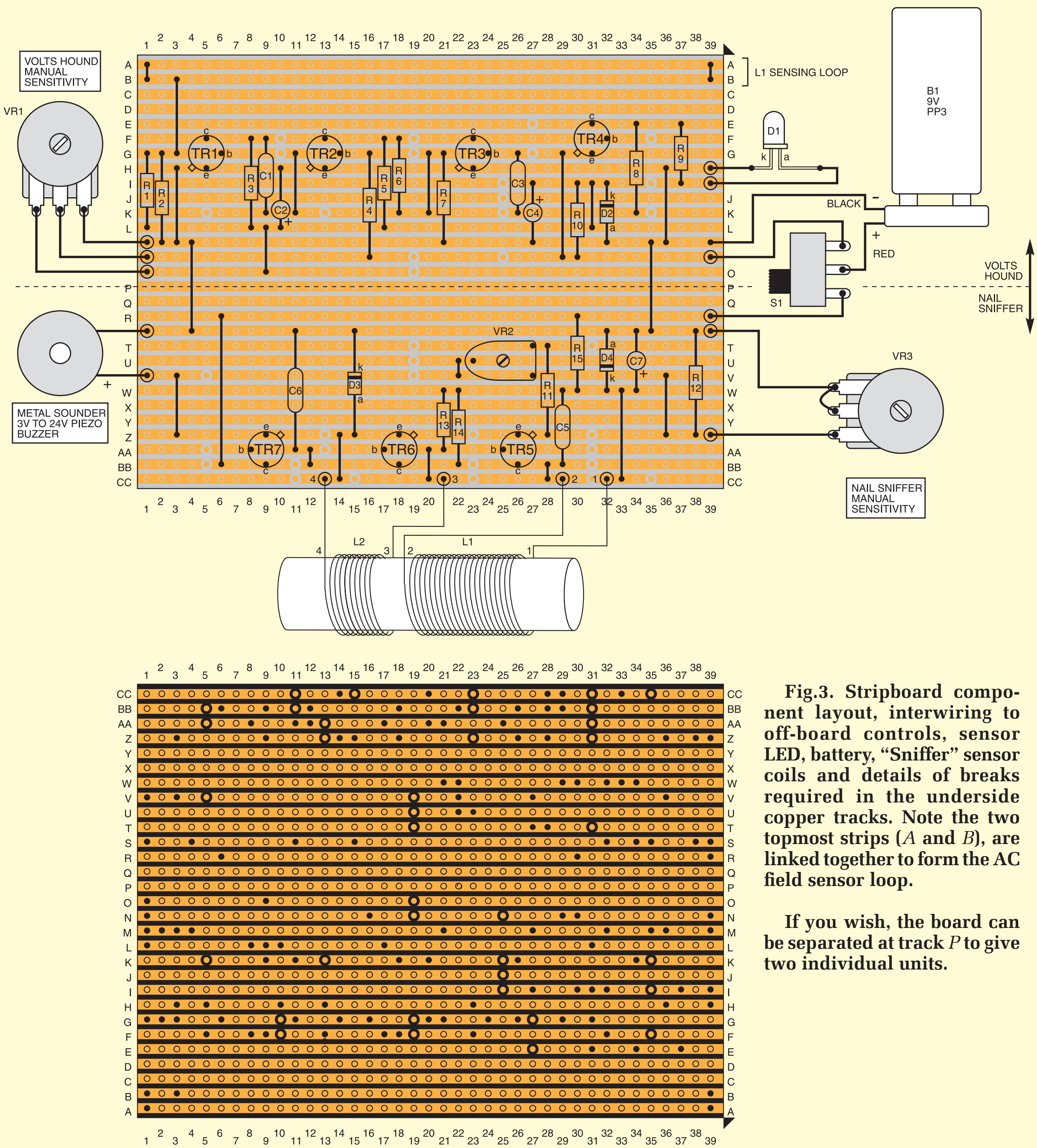


Fig.3. Stripboard component layout, interwiring to off-board controls, sensor LED, battery, "Sniffer" sensor coils and details of breaks required in the underside copper tracks. Note the two topmost strips (*A* and *B*), are linked together to form the AC field sensor loop.

If you wish, the board can be separated at track *P* to give two individual units.

Parts List – Nail Sniffer & Volts Hound

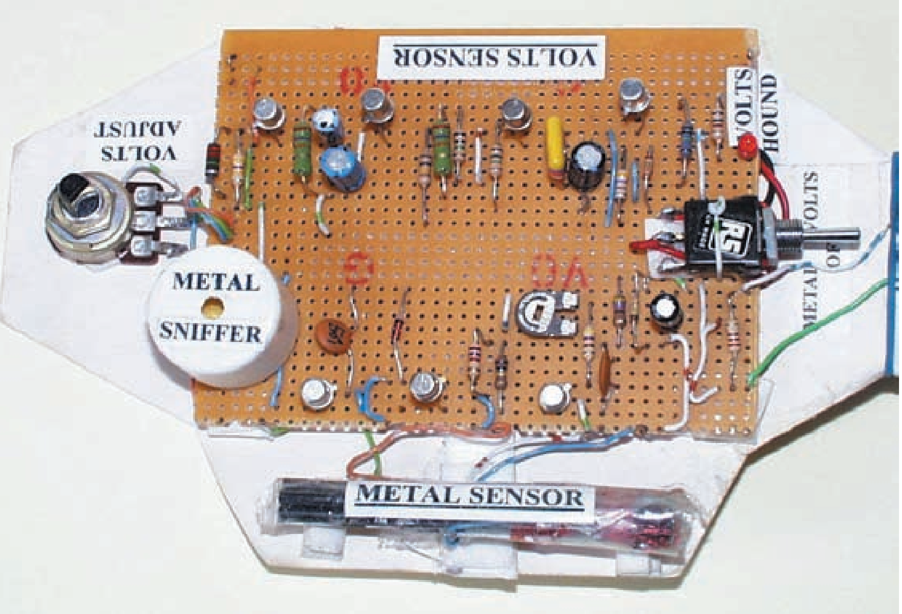
1 piece of stripboard, 39 holes by 29 tracks, size 102mm (4in.) × 76mm (3in.) approx.
1 sub-min s.p.d.t. slider or toggle switch, centre off
1 piezoelectric buzzer, 3V to 24V
1 ferrite rod, size 10mm dia. × 75mm length approx.
1 9V PP3 type battery, with clip
Five metres length 28s.w.g. to 30s.w.g. enamelled copper wire for coils L1 and L2; multistrand coloured connecting wire; single-core link wires; double-sided self-adhesive tape/pads; solder etc.

Semiconductors
1 3mm red LED
2 4V3 400mW Zener diodes
1 1N4148 signal diode
6 BC107 *npn* general purpose transistor
1 BC177 *pnp* general purpose transistor

Resistors (0·25W 5%)
1 220Ω
3 470Ω
1 1k
1 2k7
2 27k
2 100k
1 470k
3 1M
1 2M2

Capacitors
1 4n7 ceramic disc, 5mm pitch
1 47n ceramic disc, 5mm pitch
1 470n ceramic disc, 5mm pitch
1 100n ceramic disc, 5mm pitch
3 47μ radial elect. 25V

Potentiometers
1 1k min. carbon skeleton preset
1 1k carbon rotary, lin.
1 10k carbon rotary, lin.



Completed prototype circuit board mounted on a stiff cardboard "paddle/bat" cutout using double-sided self-adhesive pads

protect your hands. Lay the wire on the floor without kinks.

Cut a few short pieces of self-adhesive tape. Fasten the near end of the wire to the ferrite with a piece of tape, leaving a 5cm tail. Begin winding the first coil by rotating the ferrite rod between your thumb and finger, keeping the turns as close together as possible, and finalise with another piece of insulation tape, again leaving a 5cm tail.

Proceed as before with the second coil, being very careful to wind in the same direction as for the first coil. To keep the finished coil turns mechanically secure, apply insulation tape along their total length.

Identify and mark which coil tail is which to aid correct connection to the stripboard, as shown in Fig.3. The coils are deliberately left unscreened.

Setting-up

When setting up the Volts Hound, first keep the sensor well clear of any live a.c. mains cables. Then adjust the Sensitivity control VR1 until l.e.d. D1 switches on, thereby confirming that the circuit is functional. Now carefully re-adjust VR1 until the l.e.d. is *only just* switched off.

In this condition the circuit is at its most sensitive and will be triggered whenever the sensor is brought to within detection range of any live a.c. mains cable. To prove this, bring the unit close to the mains cable of any item of switched-off equipment. At maximum detection range the l.e.d. will flash slowly, the rate increasing as the cable is approached, until the l.e.d. lights continuously.

Setting up the Nail Sniffer is also simple. With its sensor well clear of any metallic influence, set Sensitivity control VR3 to mid-rotation. Then adjust preset VR2 until the buzzer is only just switched off. This is a once and for all adjustment.

Prior to use, carefully adjust VR3 to confirm buzzer activity and then reset until the buzzer is only just quiet. The buzzer will now sound when metal is detected within about 3cm of the search coil as it is moved over the search area. ***EPE***

Circuit Surgery

Ian Bell

Driving Multiple LEDs

READER ***Ken Barry*** wrote to ask us to discuss LED driving, particularly for large numbers of LEDs used together. He was inspired by the discussion of LEDs in *Teach-In 2006* to try to construct his house number using high brightness yellow LEDs. He writes:

My numeral 4 consisted of 37 high brightness LEDs and on the breadboard I connected them in series. Each LED dropped 0·6V and I therefore would need 68V to light them. The Ammeter registered practically zero. I therefore decided to connect them in parallel; the ammeter registered 0·25A when all were lit.

Unfortunately Ken did not give us full details of his experimental setup, such as the actual series current reading and the voltage drop for the parallel connection, or what settings gave acceptable light output. The 0·6V drop mentioned is quite a bit less than the usual forward voltage for an LED; 37 LEDs on 68V is more typical at 1·84V average per LED.

However, the choice between series and parallel driving of LEDs is an interesting issue which we will discuss this month. A key factor is obtaining even brightness across all the LEDs. Usually, we want all the LEDs to have the same brightness so that we create an aesthetically pleasing display or evenly distributed illumination.

Forward Characteristic

The typical forward characteristic curves for an LED are illustrated by Fig.1. They are for the MC5X5X and MV6X5X range of LEDs from Fairchild Semiconductor (**www.fairchildsemi.com**). Those of you following *Teach-In 2006* will be familiar with diode characteristic curves from Part 4.

Note that the Fairchid data is plotted beyond the point of the maximum continuous current (shown dotted), which is about 20mA to 30mA for these devices. This is because LEDs are quite commonly pulsed at high current levels. Higher currents can be used during pulsing because the LED has time to cool down while it is off. The Fairchild datasheet quotes maximum pulse currents for 1μs pulses at 0·3% duty cycle. We will comment more on pulse driving of LEDs later.

LEDs are current controlled devices – the light output (brightness) is just about linearly proportional to the forward current. This is illustrated by Fig.2, which is also from the Fairchild datasheet. Note this graph is for instantaneous, not continuous, forward current.

High Brightness

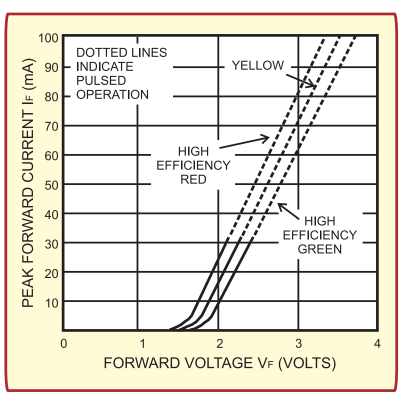
Ken says that he is using high brightness LEDs; these provide more light output for given forward current than standard LEDs. This is illustrated by Fig.3, which is from Toshiba (**www.semicon.toshiba.co.jp**) and compares their general purposes (TLO1002) and high brightness (TLOU1002) surface mount LEDs.

It is the *current* through an LED, not the *voltage*, which sets the brightness. Two individual LEDs of the exactly the same type will produce the same illumination with the same forward current (I_F), but may have different forward voltage drops (V_F) at this current. The variation in voltage drop between individual devices may be in the range 0·1V to 0·3V for typical LEDs. This is a key fact that needs to be considered when designing LED drive circuits.

This is illustrated in Fig.4, which shows possible forward characteristics for two LEDs of the same type (this is different from Fig.1, which has three curves for different devices).

The circuit in Fig.5 shows two LEDs driven in parallel using a single current limiting resistor. This circuit forces the LEDs to have the same forward voltage drop, which means that their forward currents, and hence brightness, may be different (see Fig.4).

The circuit in Fig.6 shows two LEDs with separate current limiting resistors; we can still get problems with variation between individual devices, resulting in varying brightness. An example will help explain this.



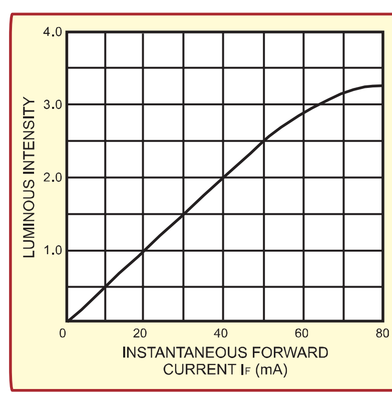
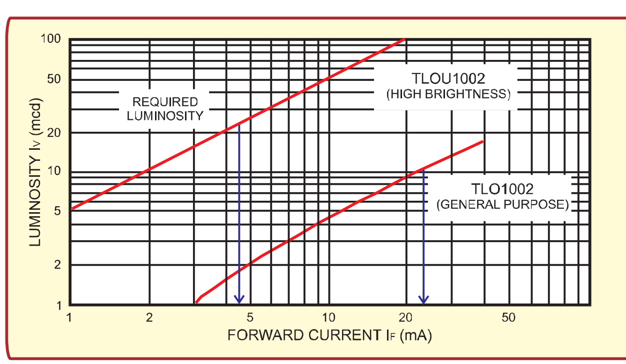


Fig.1. (above) Typical forward characteristic curves for an LED

Fig.2. (above right) Instantaneous forward current in an LED

Fig.3. (right) Typical forward currents for two high brightness LEDs



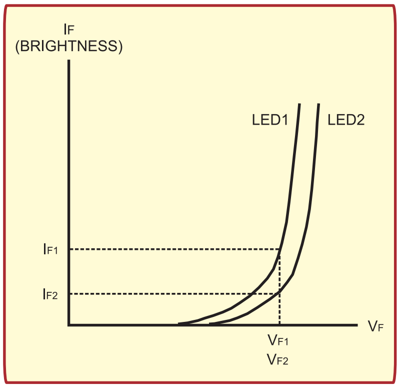


Fig.4. Possible forward characteristics for two LEDs of the same type

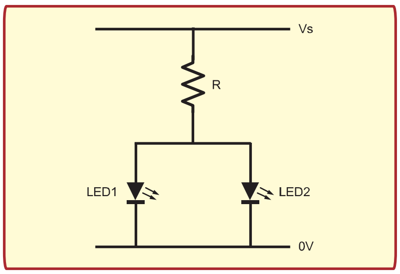


Fig.5. Two LEDs driven in parallel using a single current limiting resistor

An Example

Assume we have yellow LEDs with LED1 having a forward voltage drop of 2V at a forward current of 15mA. If the supply (V_S) is 3·5V we have R1 = 100Ω, so that R1 drops 1·5V and we have 2V across LED1. If LED2 is connected with R2 = 200Ω, but has, say, a forward voltage drop of 2·2V due to variations in individual device characteristics, the current in LED2 will be 13mA. The difference in current may show up as a noticeable difference in brightness.

If we use a higher supply voltage, the brightness variation problem is reduced. For example, consider a 20V supply. Let's say we have R1 = 800Ω to get 20mA with a 4V drop across LED1, so the LED is driven as before. Now consider LED2 with a 3·6V drop and R2 = 800Ω. The current in LED2 is 20·5mA, almost the same as LED1, so they will appear equally bright.

This comes at a high price though – the total power dissipation in the two current limiting resistors is about 0·66W in the second example, which is almost twenty times higher than in the first example. The second circuit is very inefficient and would not be very suitable for battery powered operation.

The circuit in Fig.7 shows three LEDs driven in series. The current through the LEDs must be equal so their brightness will be equal. A potential difficulty with this circuit is that a relatively high voltage is required to drive the series chain. As Ken mentioned, he needs about 68V for his 37 LEDs.

Practical Compromise

For a large number of LEDs, a compromise between parallel and series connection can reduce the need for a large supply voltage. This is illustrated by Fig.8, where

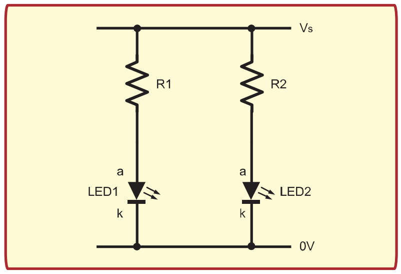


Fig.6. Two LEDs with separate current limiting resistors

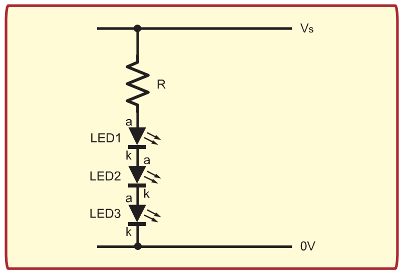


Fig.7. Three LEDs driven in series

12 LEDs are connected in three groups of four in series. For a 1·8V drop it should be possible to use a series connection of six LEDs from 12V, which should be easier to organise than 68V.

An efficient low voltage solution to the brightness variation problem is to drive each LED from a separate constant current source set to the required forward current. The current in every LED circuit can then be modulated by a single control voltage if brightness variation was required. Several ICs are available to do this, such as the Maxim MAX1916.

To drive large numbers of LEDs, series connection to a single current source is probably preferable, but returns us to the problem of needing a large voltage. The voltage of the current source output is free to vary, but it must be able to place sufficient voltage across the load or it will fail to deliver the required current.

Again there are chips that can help with this, such as the MAX8595. It includes a switched mode power supply which generates up to 38V. Using this it can drive from two to nine (white) LEDs from its constant current source. The current level can be adjusted using a control voltage, or the brightness can be modified using pulse width modulation.

The circuit diagram in Fig.9 shows a typical MAX8595 circuit taken from the Maxim data sheet (**www.maximic.com**). As with any switched mode power supply IC, the MAX8595 requires careful PCB layout and component selection. Consult the datasheet for details.

PWM Control

As we have seen with the MAX8595, as an alternative to varying forward current, LED brightness can be controlled by pulse width modulation (PWM). The LED is switched on for some of the time and off for some of the time. As the proportion of on time (pulse width) relative to off time increases, so the brightness also increases.

The pulse rate should be at least 100Hz, but much higher rates are often used. If LEDs are pulsed, a square wave should be used, sine waves result in about two thirds of the light output of an equivalent square wave.

The best average light output for human viewing is obtained by DC drive, with control of forward current used to control brightness. Short duration, high current pulsing is most appropriate when the LED is used to send a signal to a photodetector.

Switching of LEDs for human viewing is, of course, needed in applications where groups of LEDs form symbols or messages, as in a multiplexed seven-segment display. However, PWM is used quite frequently for varying LED brightness for human viewing because it is easy to implement using purely digital circuits – it does not require a DAC for a control voltage or current.

When pulsing an LED, a key parameter is the peak junction temperature of the diode. If the maximum junction temperature is exceeded the device will be damaged. For pulse rates below about 1kHz, the peak junction temperature is higher than the average temperature, so at and below this pulse rate the allowable average current is lower than at higher pulse rates.

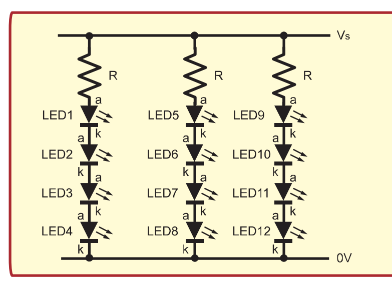


Fig.8. Example circuit for 12 LEDs connected as three groups of four in series

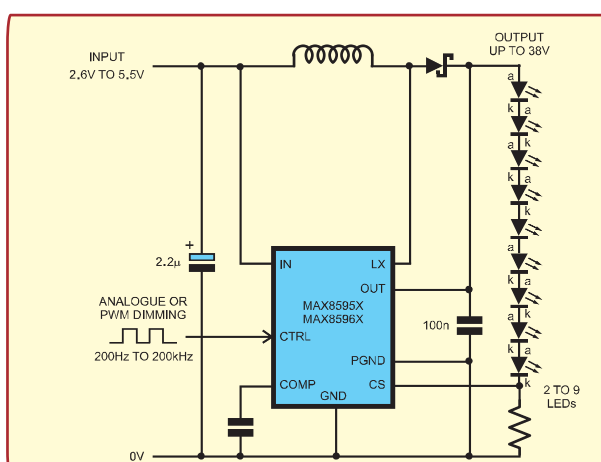


Fig.9. Using a switched mode power supply to drive nine LEDs

Replace your car's filament lamps with LEDs for improved safety

By PETER SMITH

LED Lighting For Your Car

INCREDIBLY BRIGHT Light Emitting Diodes (LEDs) are now available in standard 5mm packages – bright enough, to rival incandescent bulbs in some applications.

This month, we present five simple and easy-to-build modules based on these, ultra-bright LEDs. These modules can be used to replace or supplement a variety of existing automotive lights to improve safety.

Safer, huh?

Do you know why the centre high-mount stop lights of some vehicles use LEDs rather than conventional filament lamps? For the "high-tech" look, perhaps?

Maybe, but there's a much more important reason; LEDs reduce the incidence and severity of rear-end collisions!

So how is this possible? The answer is based on the fact that filament lamps typically take between 120ms and 250ms to 'light up' when you hit the brakes. If that doesn't sound like much, then consider the distance travelled in 200ms at 70mph/6·8yds (approx. 6·3m):

70mph x 1/3600 x 200ms x 1760 = 6·3m

Convert These to LEDs

- High-mount stop lights
- Trailer lights
- Breakdown lights
- Interior (festoon) lights
- Bayonet lamps
- Wedge lamps
- Almost anything!

Those 6·3 metres could make all the difference in an emergency braking situation – a serious accident or none at all!

The good news is that you can get that distance back with LED-based stop lamps, because LEDs 'light up' almost instantaneously. Not only that but the fast turn-on of LEDs makes them more conspicuous; they have greater attention-getting power.

LEDs have a number of other advantages over filament lamps, too. They load vehicle electrical systems by at least one third less, generate little heat, require *less* space and have a very long service life.

With all these positives, it seems ludicrous that new vehicles still aren't fitted with the latest high-brightness LED technology even in the centre high-mount stop light (CHMSL).

You can now convert your old-technology CHMSL to the latest and greatest with the aid of our LED CHMSL module and a few simple tools.

This particular module consists of a single, 150mm-long PC board strip carrying 16 high-intensity red LEDs, four resistors and two diodes. It should fit inside most CHMSL housings without too much difficulty, replacing the standard 21W filament lamp. But before we describe how that's done, let's take a look at how it works.

How the modules work.

All modules are of the simplest design possible. They consist of one or more strings of LEDs, current limiting resistor(s) and in most cases a diode or two as well.

Referring to the circuit diagram for the CHMSL module (Fig.1), you can see than the LEDs are arranged in four strings. Each string consists of four LEDs in series with a current limiting resistor. The resistor sets the current through the string, as follows:

$$I = V/R$$
$$= V_{BATT} - V_{DIODE} - (4 \times V_{LED}) / R$$
$$= 12{\cdot}8V - 0{\cdot}7V - (4 \times 2{\cdot}0V) / 150\Omega$$
$$= 27{\cdot}3mA$$

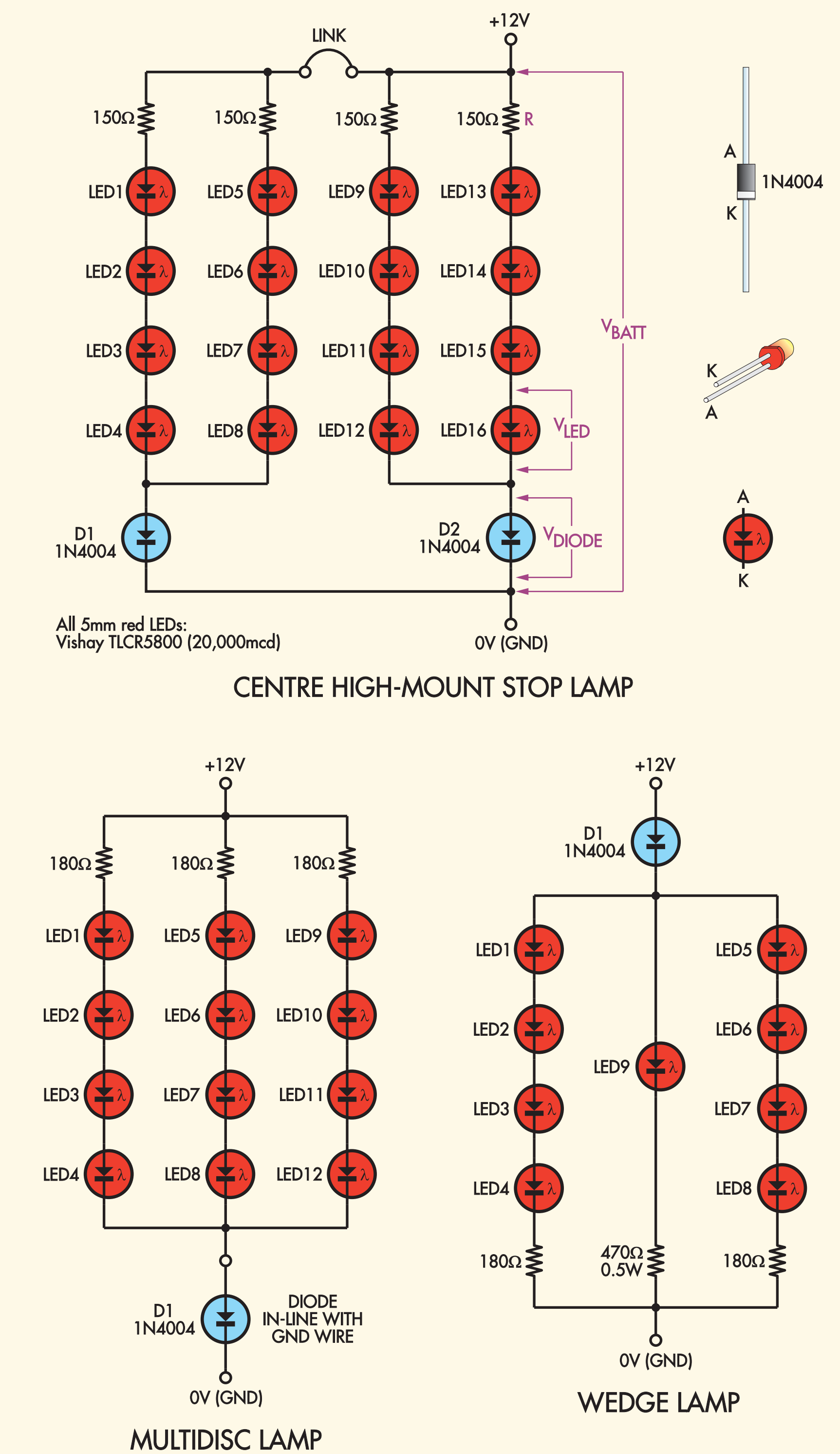
V_{LED} is the forward voltage of the LEDs at the intended current, in our case about 27mA. This value will vary between LED types, so you may need to adjust your resistor values for optimum results.

Although the high-brightness red LEDs we've specified can be driven at much higher current levels (up to 50mA), we recommend derating to a maximum of 30mA to allow for the high temperatures found in automotive interiors. If you're using different LEDs, then derate even further to 25mA.

V_{DIODE} is the forward voltage of the 1N4004 diode. The purpose of this diode is to protect the LEDs from the large negative voltage transients (up to 400V) often present in automotive electrical systems.

Typical LED reverse breakdown voltage is somewhere in the region of 5 to 6V, so with four LEDs in series the best we could hope to "stand off" without the additional diode would be about 24V.

In cases where there are less than three LEDs in a string, the 1N4004 also provides reverse polarity protection. Without protection, accidental lead reversal could cause your LED bank to glow brighter than the Sun for a few milliseconds!



AUTOMOTIVE LED LAMP MODULES

Fig.1: circuit diagrams for all of the red LED modules. Note that we've reduced LED current on the Multidisc and Wedge lamp modules by increasing the resistor values from 150Ω to 180Ω. This is to allow for the higher temperatures present in tightly grouped LED arrays.

An example

Let's look at an example. Suppose you're using different LEDs to those

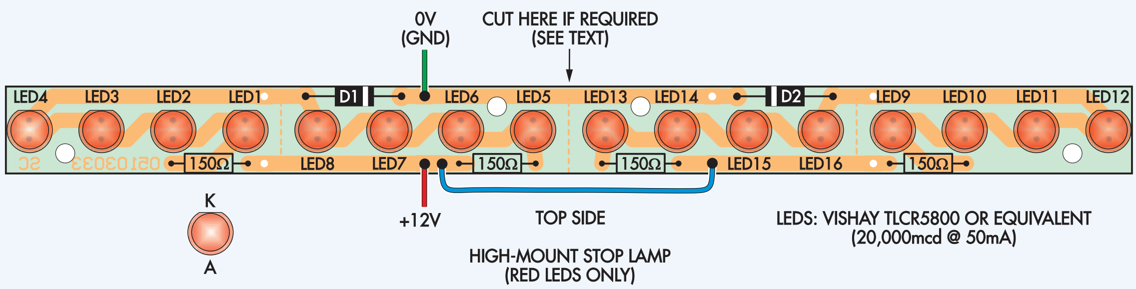
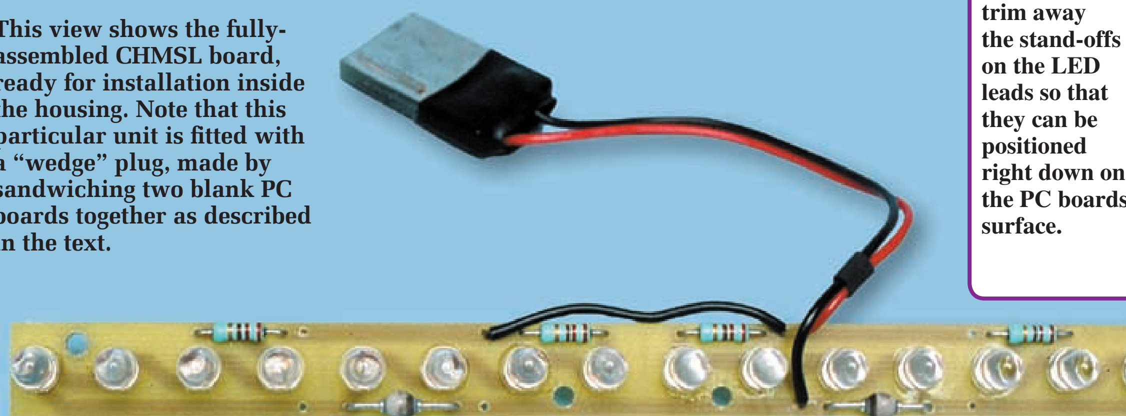
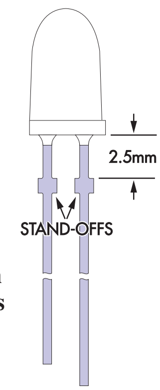


Fig.2: follow this diagram when assembling your centre high-mount stop lamp board.



This view shows the fully-assembled CHMSL board, ready for installation inside the housing. Note that this particular unit is fitted with a "wedge" plug, made by sandwiching two blank PC boards together as described in the text.

Fig.3: you may need to trim away the stand-offs on the LED leads so that they can be positioned right down on the PC boards surface.



shown in the parts list and you've determined that they drop about 1·8V at 25mA (the forward voltage can be determined from the LED data sheets or by trial and error). What value resistors would you use on the CHMSL module?

R = V/I
= 12·8V – 0·7V – (4 x 1·8V) / 25mA
= 196Ω

The closest readily available value to 196Ω is 200Ω, so that would be your final choice. A 0·25W power rating is sufficient in most cases.

So far, we've only talked about the CHMSL module but there is little difference in operation between the five modules. Some have less LEDs per string, some have just one (the 10mm LED on the wedge lamp, for example) and one requires the diode to be fitted externally.

Note, however, that we've listed LED colours with each module. This is because white and blue LEDs have a significantly higher forward voltage than red (and other colours) and therefore will not work on modules that have four LEDs in series.

Likewise, reds (and other colours) cannot easily be used on the modules specified for white and blue without considering the increased resistor power dissipation requirements.

CHMSL module assembly

Referring to the overlay diagram in Fig.2, begin by installing the two diodes and four resistors. Take care with diode orientation, noting that D1 and D2 go in different ways around.

Next, install all 16 LEDs, aligning the side with the 'flat' (the cathode) as indicated. This should also be the side with the shorter lead. We mention this because some 10mm LEDs we received were incorrectly polarised; the flat side was next to the anode (longer lead). If you're not sure, use your multimeter on "diode test" to verify polarity.

The LEDs should be seated right down on the PC board surface. Some LEDs have large standoffs formed into their leads, making this impossible. If you have this problem, then measure between the underside of the LED and the start of the standoffs (see Fig.3). If you measure 2·5mm or more, then you can cut the leads off right at the edge of the standoffs, as there will be sufficient length remaining for soldering. Try just one LED first, though!

If the standoffs are closer than 2·5mm to the body, then shorten the leads to about 4mm and using a fine-edged pair of electronics side-cutters, carefully snip away the shoulders of the standoffs (see Fig.3).

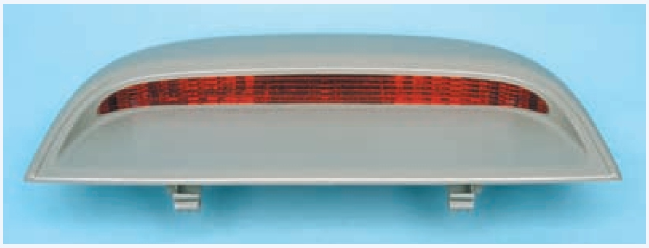
WARNING

If you have a recent-model car, it may have a lamp failure detector in the brake lamp circuit. If you convert just the CHMSL to LED operation, it is unlikely to be affected. However, if you also convert the stop lamps to LED operation, the lamp failure detector will almost certainly operate each time you press the brake pedal. The fault may even be recorded in the computer's diagnostic memory.

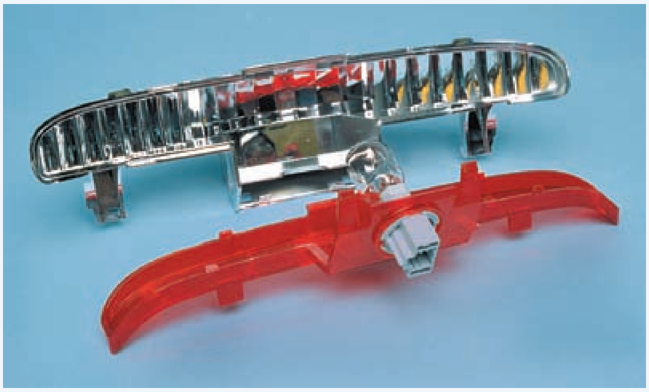
In some older prestige cars, such as some Lexus models, the CHMSL also has a lamp failure detector and it will "detect" a lamp failure if the LED conversion is present. At present, we have no solution for this problem.

Converting A High-Mount Stop Light To LEDs

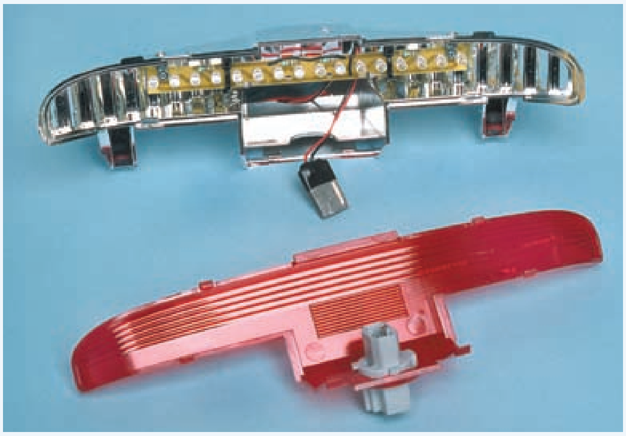
Fitting the CHMSL module (shown at left) to an existing housing can be achieved with a little ingenuity. Here's how we did the job on a Honda Accord.



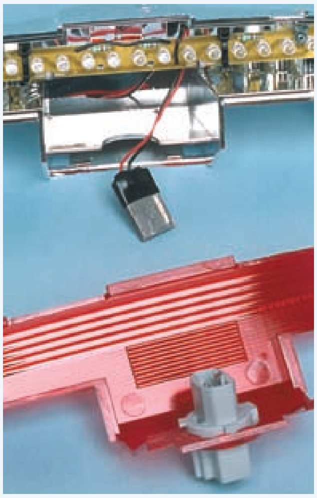
(1). The Accord's CHMSL sits on the parcel shelf and is retained with two clips accessible from within the boot space. The entire assembly came away in less than 10 seconds!



(2). Once we had the assembly on the bench, it was a simple matter to separate the red lens from the reflector to get to the insides. Be careful with the clips that hold these parts together, as the plastic is very brittle.



(3). In our case, the replacement LED module was just the right length for the job. We made a couple of small right-angle brackets to hold the board and screwed these to the top of the reflector. Many other mounting methods are possible, depending on shape and available space; eg, nylon standoffs, cable ties, M2.5 screws, silicone sealant, etc. Make sure that the rear of the PC board cannot contact anything metallic, though.



(4). We didn't want to modify the vehicle's wiring, so we powered the LED module directly from the old filament lamp socket. A suitable plug can be fashioned from two pieces of PC board, some glue and a length of tinned copper wire (see wedge lamp details). Be sure to tin all bare copper areas to prevent corrosion.

To finish, install the +12V link and two 150mm flying leads for the +12V and 0V connections. Any light duty multistrand hook-up wire will do.

CHMSL module installation

We chose a Honda Accord for our prototype installation – see photos. We didn't hack off any "unnecessary" bits along the way, thus allowing return to the standard filament lamp configuration if need be. Adapt our methods to suit your particular vehicle.

If the module is too long for your housing but there is plenty of vertical space, then you can cut it in half and mount one section directly above the other. This is possible because we've designed the two sides of the board in "mirror image". These smaller sections could be useful for other applications as well.

Multidisc module assembly

As the name suggests, the Multidisc module has multiple uses, some of which will require the PC board to be circular in shape see Fig.4.

Install the LEDs, aligning all cathodes (flat sides) towards the centre of the board. The LEDs must be mounted right down on the PC board surface. If your LEDs have large standoffs that prevent this, then refer to the assembly instructions for the CHMSL module for the solution.

Install the three resistors next. Now turn the board over to the copper side and install an insulated wire link as shown on the overlay diagram (Fig.4). Finally, solder two lengths of light duty hook-up wire to the +12V (+) and 0V (-) points and pass the ends through the cable hole.

Unlike the other modules, this one doesn't have a diode in series with the supply. We recommend installing a 1N4004 diode in series with either the positive or negative lead and insulating it with heatshrink tubing.

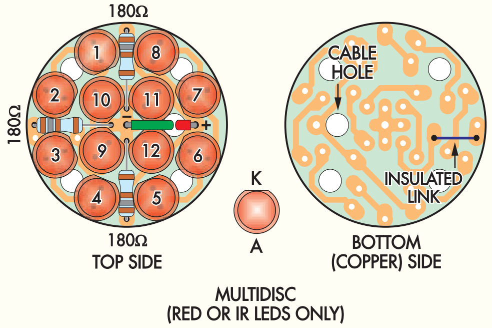


Fig.4: the overlay diagram for the Multidisc module. Form the leads of each resistor so that its body sits directly between adjacent LEDs.

Bayonet lamp assembly

Below are the instructions for the bayonet lamp assembly, presented in a step-by-step format to help make the job easier – see Figs.5 & 6.

(1). Remove the glass bulb and filament from a standard 21W automotive bayonet lamp. Clean the glue from around rim of base and several millimetres into the interior. Polish the area with a fine scouring pad or ink rubber and clean with alcohol.

(2). Remove solder from the tip.

(3). Cut a standard 14·5mm outside diameter copper water pipe joiner in half and chamfer one end with a file. Polish the tube with a fine scouring pad or ink rubber and clean with alcohol. Insert the tube 2 to 3mm into the base rim and solder in place.

(4). Centre the Platform PC board over the end of the tube and solder in place. Apply your iron to the copper tube rather than the PC board so as not to overheat the latter.

(5). Trial fit an assembled Multidisc module on the Platform board to determine the required lead length. Trim the +12V wire to length and strip and tin the end. Pass it through the centre hole in the Platform board and solder it to the base tip, building up the solder as needed to get a nicely curved "bump".

(6). Pass the 0V (GND) wire through the outer board hole and trim to 10 to 15mm in length. Strip and tin the end.

(7). Trim both leads of a 1N4004 diode to about 6mm in length and solder the anode end to the 0V (GND) wire. Slip a length of heatshrink tubing over the diode to insulate the connection. Solder the other (cathode) end of the diode to the underside of the Platform PC board.

(8). Attach the Multidisc assembly to the Platform board using small cable ties, or for a more permanent job, use several 'blobs' of silicone sealant.

Wedge lamp "skeleton" assembly (Fig.7)

(1). Prepare the blank (non-copper) sides of two wedge PC boards so that all edges are free of burrs and the surfaces are completely smooth and clean.

(2). Bond the blank sides together (copper sides facing out) using a very thin smear of cyanoacrylate-based adhesive. Pay particular attention to alignment; the boards must be exactly aligned, such that they appear to be one single unit after bonding.

(3). Touch up the sides with a fine file to bring the edges into perfect alignment. Also, file the shoulders if necessary to ensure that they are horizontal and in-line.

(4). Trial fit the assembly to a wedge lamp socket. A small chamfer on the leading edges of the wedge assembly may make insertion easier.

(5). As supplied, the Disc PC board may have a series of three holes rather than a slot in the middle. You'll need to file a slot that is just large enough to accept the head of the wedge assembly. Make the fit as firm as possible. You may also need to cut and/or file the board outline into a circular shape.

(6). Assemble the boards, making sure that the shoulders of the wedge assembly firmly contact the underside of the Disc board. Solder the three pads on the wedge assembly to the pads on the underside of the Disc board. Repeat for the second side. If the Disc board is double-sided (has copper on both sides), then repeat on the top side.

(7). Mount all components as per the overlay diagrams in Fig.8 and the text that follows.

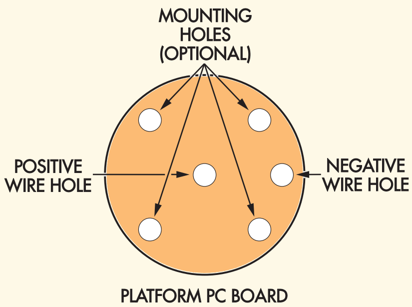


Fig.5: the Platform PC board is unetched (blank copper). To make one, cut the 26·5mm disc from blank circuit board material and drill six 2·5mm holes as show here. The Multidisc PC board can be used as a template.

Wedge lamp assembly

With the wedge lamp "skeleton" complete, it's time to mount all the components. Begin with the eight 5mm LEDs on the Disc board, aligning the cathode (flat) sides towards the centre of the board.

Fit the 10mm (centre) LED last. The flat (cathode) side must be aligned towards the "dot" side of the board. The "dot" side is marked with a small copper dot (pad without a hole) on the underside. Form the leads as shown in Fig.7 and push the LED down until it makes contact with the head of the wedge board assembly.

Bayonet Lamp Assembly Details

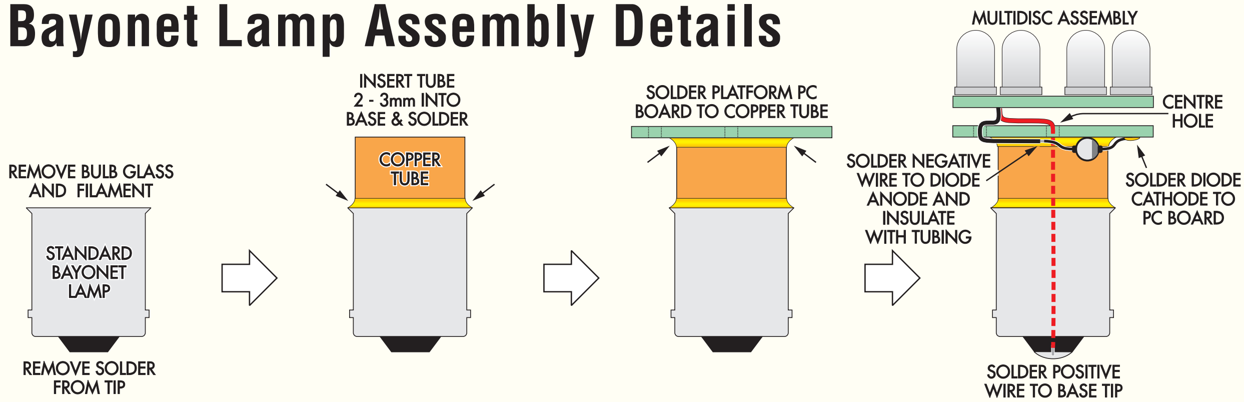


Fig.6: follow this diagram and the step-by-step instructions in the text to make the Bayonet lamp assembly. The Multidisc assembly can be fixed in place with silicone sealant.

The three resistors and the 1N4004 diode can go in next (see Fig.8). Note that it is vital that these components go on the right sides of the wedge assembly. As shown in Fig.7, the resistors mount on the "dot" side and the diode on the other.

Component mounting is unconventional in that the leads should not pass through both PC boards and protrude from the opposite side. The PC board holes have been deliberately offset to prevent this from happening. You'll need to bend the leads of each component and trial fit it in place, trimming back lead lengths just enough so that they enter their respective holes before soldering in place.

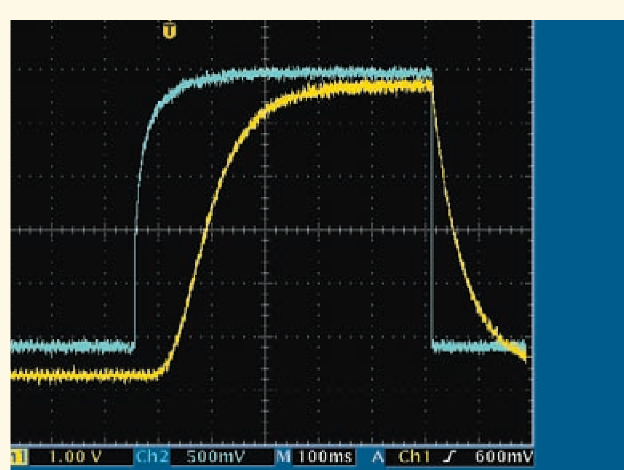
Finally, solder lengths of tinned copper along the tracks exactly as shown in Fig.8. The vertical lengths at the bottom take the place of the filament lead-outs on the base of a wedge lamp and need to be positioned so that they mate with the contacts in the wedge socket. The horizontal lengths replace the "bump" on the wedge bulb base that is captured by

The LED bayonet lamp is made by scrounging the base from a conventional bayonet lamp and fitting it with a Multidisc module. Note that the latter sits on top of a Platform PC board (the two are secured using silicone sealant).

Response Times: LEDs Versus Conventional Filament Lamps

After upgrading the Honda's CHMSL to LEDs, we decided to "get technical" and actually measure the difference in response between the old and the new. We made up a couple of phototransistor-based sensors and positioned one behind the CHMSL and the other behind one of the stop lights. Our Tektronix scope captured the waveforms at right when we tapped the brake pedal.

As you'd expect, the blue trace represents the LED CHMSL light output whereas the yellow represents the conventional stop light. A rough estimate shows the filament lamp to be about 150ms behind the LEDs, with full brilliance at least 200ms later. The rounding on the leading edge of the LED waveform is caused by voltage drop in the wiring loom, a result of the stop lamps' cold filament current, which momentarily exceeds about 40A.



Wedge Lamp Skeleton

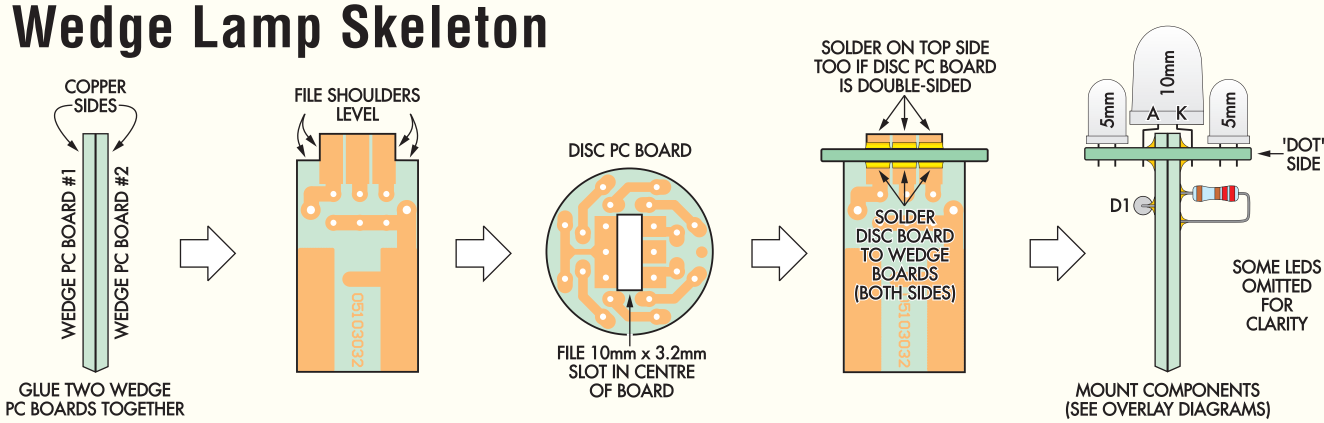


Fig.7: here's how to put together the Wedge lamp "skeleton". After soldering the Wedge and Disc boards together, inspect your work for potential solder bridges between pads. This is only important on the "dot" side, as all pads on the opposite side will be connected with a wire link anyway (see Fig.8).

a spring clip in the socket in order to retain the bulb.

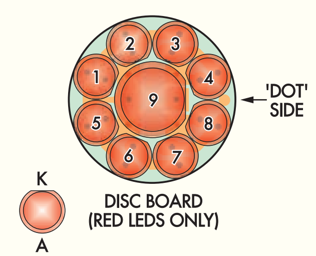
Festoon lamp assembly

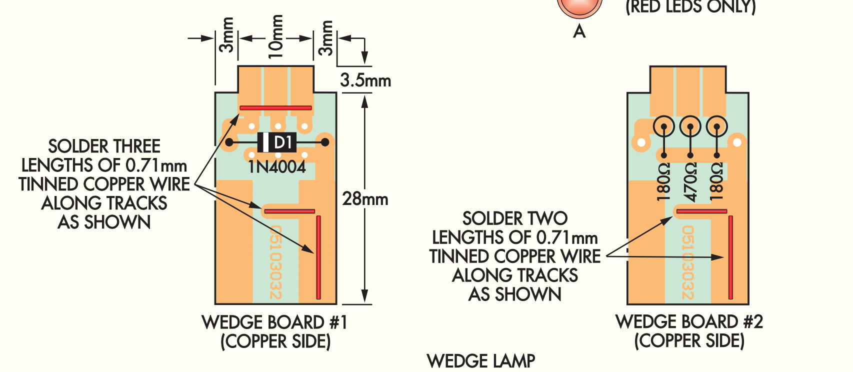
This LED equivalent of the festoon (interior) lamp can be built in either a 31mm (2 LED) or 41mm (3 LED) version. As mentioned previously, you have the choice of using either white or blue LEDs.

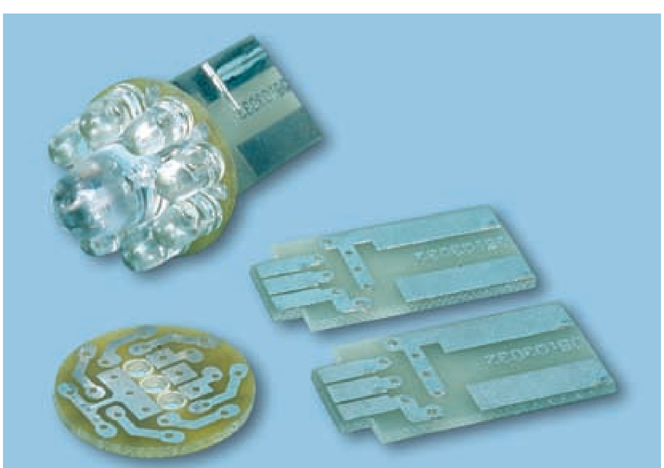
Referring to Fig.10, begin by installing the LEDs, aligning the flat (cathode) sides as shown. Be sure that you have the PC board oriented as shown on the overlay; the positive side must be on the left. The "+" and "-" symbols on the copper side allow you to determine correct polarity.

Now flip the board over and install the resistor and diode on the copper side. Both of these components should be insulated with heatshrink tubing to prevent short circuits. However, only

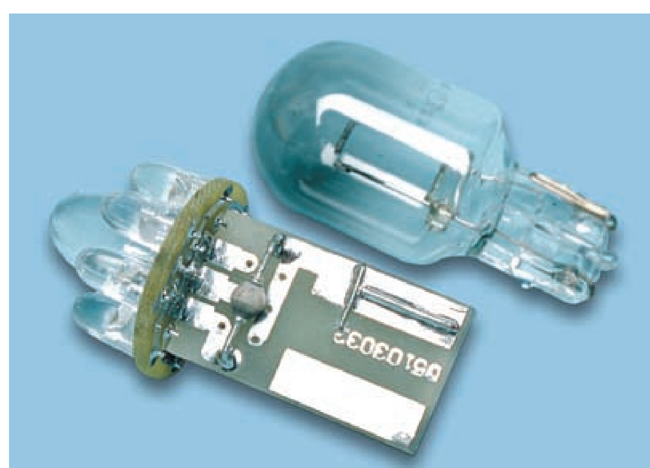
Fig.8: the Wedge lamp assembly details. Be sure to assemble the "skeleton" before mounting any of these components. Orientation of the Disc board can be determined by a dot on the copper side. This, strangely enough, is the "dot" side!







The wedge lamp is made up using the Disc board and two identical Wedge boards. It all goes together as shown in Figs.7 & 8.



The LED-powered wedge lamp can be used to replace a conventional filament lamp in some situations and will generate much less heat.

31mm & 41mm Festoon Lamp Assemblies

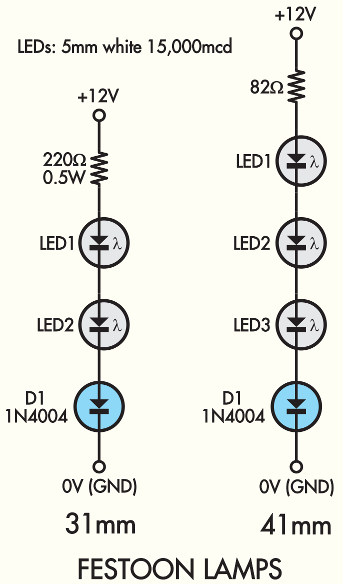


Fig.9: the circuit details for the 41mm & 31mm festoon lamps.

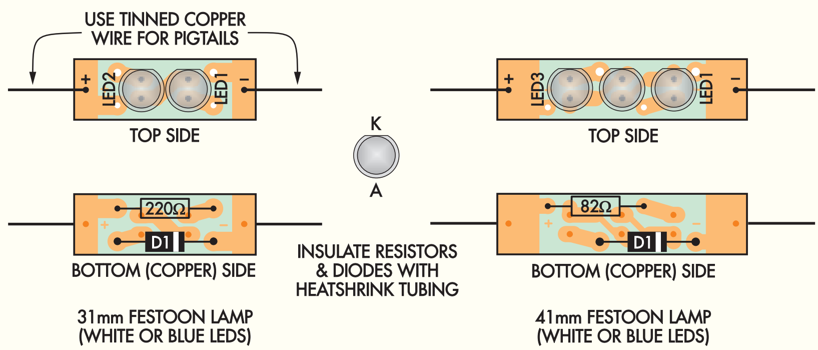
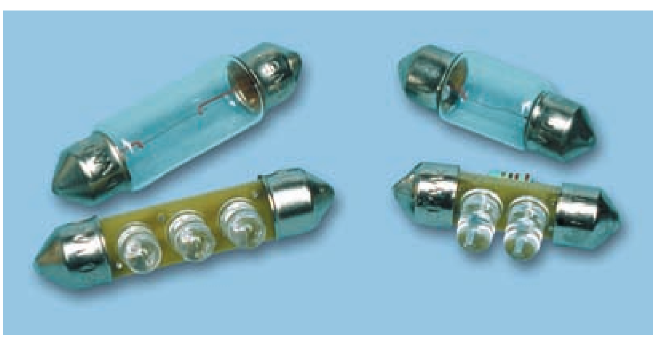
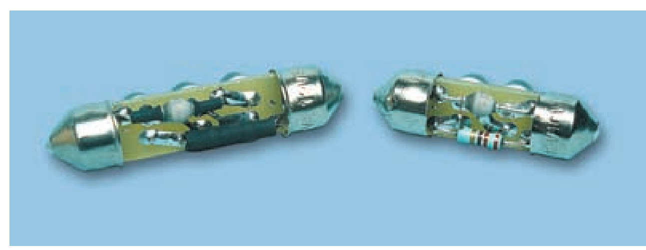


Fig.10: the assembly details for the 31mm (left) & 41mm (right) festoon lamp modules. The end caps are soldered to the PC boards after the parts have been installed.



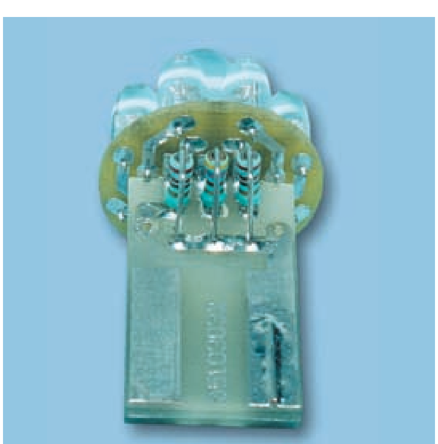


The completed festoon lamp assemblies can be plugged straight into a conventional festoon lamp holder but must be oriented with the LEDs facing outwards.

the leads of the resistor should be insulated (not the body), otherwise heat dissipation will be impaired.

Next, solder 10mm lengths of 0·71mm tinned copper wire to each end of the board, forming axial “pigtails”. These wires will make the connections to the end caps.

With the board assembly complete, the next step is to fit the end caps.



The three current-limiting resistors are mounted vertically on the wedge assembly and can be insulated with heatshrink tubing if desired.

The diode goes on the other side of the wedge assembly. The three long pads on both wedge boards are soldered to matching pads on the disc board.

Begin by removing the glass cylinder and filament from a standard festoon lamp. Take care to remove all glass fragments from inside the caps.

Desolder the holes in the cap peaks and then slip them over the pigtails. Push the PC board as far as it will go into each end cap. The assembled size should be close to the 31mm (or 41mm) mark. Snip the wires off so that they only just protrude through the cap peaks. Now solder in place and smooth off with fine glasspaper or similar.

Check that your completed lamp works in-situ and, assuming all is well, fill the end caps with 5-minute epoxy glue to make the job permanent.

Automotive lamps vs. LEDs

The extremely narrow emission angle of these ultra-bright LEDs (4°) makes them well suited for use in high-mount stop lights. However, in the case of conventional tail, stop

Parts List

High-Mount Stop Lamp (HMSL) Module

1 PC board, 11·45mm x 149·2mm
16 5mm 20,000mcd red LEDs (LEDs1-16) (Vishay TLCR5800 or similar)
2 1N4004 diodes (D1, D2)
4 150Ω 0·25W 1% resistors
200mm length of red light-duty hookup wire
150mm length of black light-duty hookup wire

Multidisc Module

1 PC board, 26·5mm diameter
12 5mm 20,000mcd red LEDs (LED1 - LED12) (Vishay TLCR5800 or similar)
1 1N4004 diode (D1)
3 180Ω 0.25W 1% resistors
10mm length of 0·71mm tinned copper wire
20mm length of 5mm-diameter heatshrink tubing
150mm length of red light-duty hookup wire
150mm length of black light-duty hookup wire

Wedge Lamp

1 PC board, 22mm diameter (Disc)
2 PC boards, 31·5mm x 16mm (Wedge)
8 5mm 20,000mcd red LEDs (LEDs1-8) (Vishay TLCR5800)
1 10mm 6,000mcd (min.) red LED (LED9)
1 1N4004 diode (D1)
1 470Ω 0·5W 1% resistor
2 180Ω 0·25W 1% resistors
60mm length of 0·71mm tinned copper wire
Cyanoacrylate-based adhesive (super glue)

Bayonet Lamp

1 assembled Multidisc module
1 PC board, 26·5mm diameter (Platform)
1 14·5mm outside diameter copper water pipe joiner
1 12V 21W single filament automotive bayonet lamp

31mm Festoon Lamp

1 PC board, 8mm x 24mm
2 5mm 15,000mcd white LEDs (LED1, LED2)
1 1N4004 diode (D1)
1 220Ω 0·5W 1% resistor
1 31mm automotive festoon lamp
20mm length of 0·71mm tinned copper wire
35mm length of 5mm diameter heatshrink tubing
5-minute epoxy

41mm Festoon Lamp

1 PC board, 8mm x 33mm
3 5mm 15,000mcd white LEDs (LED1 - LED3)
1 1N4004 diode (D1)
1 82Ω 0·25W 1% resistor
1 41mm automotive festoon lamp
20mm length of 0·71mm tinned copper wire
35mm length of 5mm-diameter heatshrink tubing
5-minute epoxy

and turn indicators, there are some potential visibility issues.

When viewed on-axis, a tight grouping of these LEDs certainly appears to equal (or even surpass) the intensity of a 21W filament bulb. The bulb, however, emits light over a much larger area, resulting in good visibility over more than 180°.

Naturally, the reflector and diffuser in light housings is designed to take this into account, so if we were to simply switch the standard bulb for a bunch of LEDs, the resultant light pattern would be entirely different.

Simply put, direct replacement of filament lamps with LED lamps in existing automotive tail, stop and turn assemblies will not always be possible. This applies particularly to "wraparound" styles, which must provide light to both the rear and side of the vehicle. This problem is easily solved by designing the assemblies specifically for LEDs, a task best left to the experts.

Having said that, we believe that our modules have a multitude of highly practical uses. Here are just a few examples:

Where to use LED lamps

Why not add a centre-mount stop light to your trailer or caravan? The small size and shape of the Multidisc module will allow it to fit neatly within commonly available trailer stop light assemblies. Do you own a motorcycle? What about a truck? Get noticed!

Printed Circuit Boards

Due to the size of the PC boards used in these designs we have decided to make them available in sets in order to achieve a sensible price for them – individually they work out relatively expensive.

The set, code 568 – available from the *EPE PCB Service* comprises two sets of boards for the Wedge Lamp (six boards in all), one High Mount Stop Light board, two each of the 31mm and 41mm Festoon Lamp boards and two sets of boards (4 boards) for the Multidisc plus platform (Bayonet Lamp).

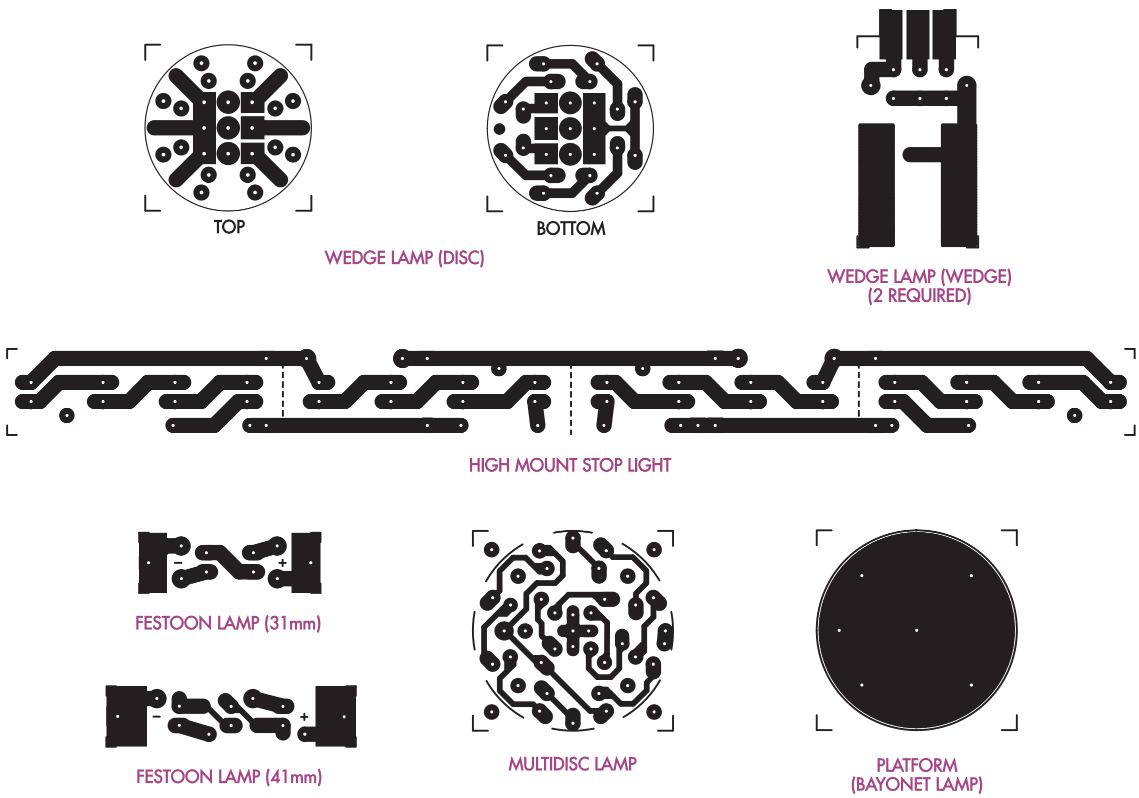


Fig.11: here are the full-size etching patterns for all the PC boards. Check your boards carefully for defects before installing any parts.

A couple of these hooked up to a simple flasher circuit and mounted under the boot lid or on a moveable panel would make the ultimate emergency beacon for late-night breakdowns. They will flash for days without running your battery flat!

In addition, the Multidisc module could be fitted with IR LEDs for use with CCD cameras and night viewers.

The LED festoon lamps don't put out as much light as the originals but they don't get hot and they won't run your battery flat in a hurry. Fit a couple under the hood, in the boot, along the floor line or in the door panels. For that high-tech look, try blue (or even true green) LEDs instead of white.

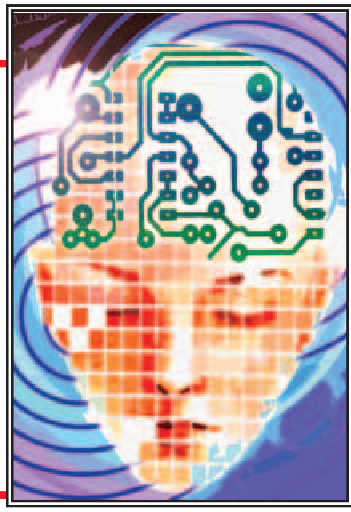
If you don't want to modify existing light housings, then the LED wedge or bayonet lamps are a good option. They're plug-in replacements for two popular auto lamp styles. If your vehicle uses different lamp styles, then you may be able to modify our designs to come up with something suitable.

Have fun! *EPE*

Although not readily apparent from the photo, the modified high-mount stop lamp with the LEDs is brighter than the conventional left-hand & right-hand stop lamps. Its response time is quite a bit shorter as well (ie, it turns on much faster when the brakes are applied).

EPE Tutorial Series

TEACH-IN 2006



Part Seven – Test and Measurement: Meters, Ohmmeters, Oscilloscopes, Waveforms, Distortion and Frequency Response Testing.

MIKE TOOLEY BA

Our Teach-In 2006 series provides a broad-based introduction to electronics for the complete newcomer. The series also provides the more experienced reader with an opportunity to "brush up" on topics which may be less familiar. This month we shall be taking a short breather from circuit theory to look at how test equipment is used to make measurements on practical circuits

We begin by looking at how we use meters to measure voltage (V), current (A) and resistance (Ω) before moving on to using oscilloscopes – both real and "virtual". Our two Practical Investigations this month will show you how to investigate simple waveforms and frequency spectra using some handy "virtual test instruments".

Meters

Straightforward measurements of voltage, current and resistance can provide useful information on the state of almost any circuit. To get the best from a meter it is not only necessary to select an appropriate measurement function and range, but also to be aware of the limitations of the instrument and the effect that it might have on the circuit under investigation. Note that, when fault finding, it is the *interpretation* that is put on the meter readings rather than the indications themselves that becomes important.

We first introduced the analogue multimeter in Part 2. This instrument is based on a moving coil meter like that shown in Fig.7.1. A current flowing in the coil suspended in a radial magnetic field produces a deflecting torque that is balanced by the two hair springs. The pointer moves over a scale that is calibrated in terms of current or voltage, depending upon the range selected on the instrument.

Photo.7.1. A selection of typical bench test instruments including a signal generator, digital and analogue multimeters, and an oscilloscope

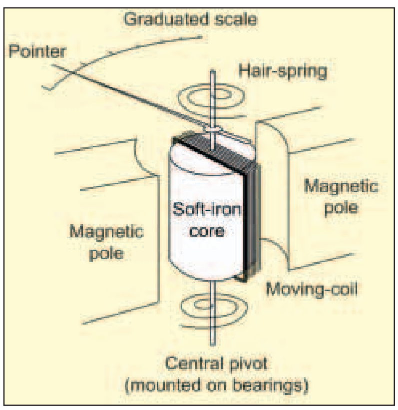


Fig.7.1. Moving coil meter construction

In order to use the basic moving coil meter as a voltmeter it is necessary to connect a resistance in series with the meter, as shown in Fig.7.2a. The series resistance acts as a "current limiter" and is known as a *multiplier*.

When we need an ammeter instead of a voltmeter it is necessary to connect a resistance in parallel with the meter as show in Fig.7.2b. The parallel resistance acts as a "current bypass" and is known as a *shunt*.

In order to determine the value of multiplier or shunt resistance (R_M and R_S respectively in Fig.7.2) it is important to remember that the coil of the moving coil meter also has a resistance. We have shown this as a resistor, *r*, connected in place of the moving coil in Fig.7.2. In both cases,

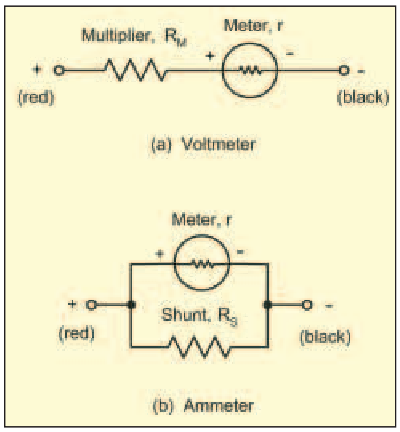


Fig.7.2. Using a moving coil meter as (a) a voltmeter and (b) an ammeter

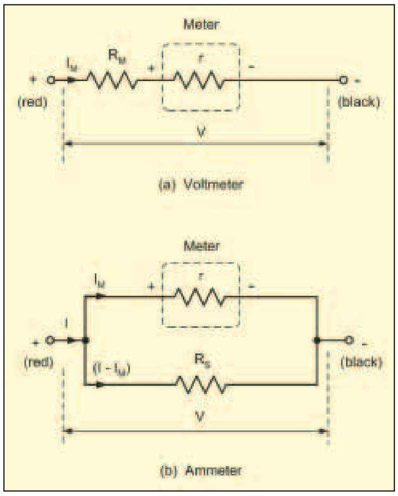


Fig.7.3. Equivalent circuit of (a) the voltmeter and (b) the ammeter shown in Fig.7.2

the current required to produce full-scale deflection (fsd) of the meter movement (and flowing in *r*) is I_M. To understand what's going on here it can be useful to refer to an equivalent circuit (see Fig.7.3) showing the current and voltage present.

In the voltmeter circuit shown in Fig.7.3a:

$$V = I_M R_M + I_M r$$

from which:

$$I_M R_M = V - I_M r$$

Thus:

$$R_M = \frac{V - I_M r}{I_M}$$

In the ammeter circuit shown in Fig.7.3b:

$$(I - I_M) R_S = I_M r$$

from which:

$$R_S = \frac{I_M r}{I - I_M}$$

Example 7.1

A moving coil meter has a full-scale deflection current of 1mA. If the meter coil has a resistance of 100Ω, determine the value of the multiplier resistor if the meter is to be used as a voltmeter reading 0V to 5V.

Using $R_M = \frac{V - I_M r}{I_M}$ gives:

$$R_M = \frac{5 - (1 \times 10^{-3} \times 100)}{1 \times 10^{-3}} = \frac{5 - 0{\cdot}1}{1 \times 10^{-3}}$$

$$= 4{\cdot}9 \times 10^3 = 4{\cdot}9\text{k}\Omega$$

Example 7.2

A moving coil meter has a full-scale deflection current of 10mA. If the meter coil has a resistance of 50Ω, determine the value of shunt resistor if the meter is to be used as an ammeter reading 0mA to 100mA.

Using $R_S = \frac{I_M r}{I - I_M}$ gives:

$$R_M = \frac{10 \times 10^{-3} \times 50}{100 \times 10^{-3} - 10 \times 10^{-3}} = \frac{500 \times 10^{-3}}{90 \times 10^{-3}}$$

$$= \frac{500}{90} = 5{\cdot}55\Omega$$

Check Point 7.1

In order to use a moving coil meter as a voltmeter it is necessary to connect a *multiplier* resistor in series with it. In order to use a moving coil meter as an ammeter it is necessary to connect a *shunt* resistor in parallel with it.

Ohmmeters

The circuit of a simple ohmmeter is shown in Fig.7.4. The battery, B, is used to supply a current that will flow in the unknown resistor, R_X, which is indicated on the moving coil meter. Before use, the variable resistor, VR1, must be adjusted in order to produce full-scale deflection (corresponding to zero on the ohms scale). This adjustment is needed because the battery voltage will fall during its service life.

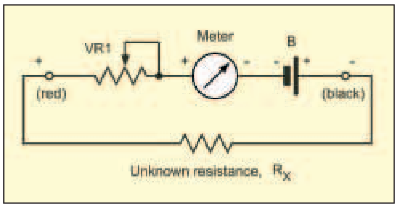


Fig.7.4. Using a moving coil meter as the basis of an ohmmeter

Note that maximum indication corresponds to zero resistance and minimum indication (no deflection) corresponds to infinite resistance (or open-circuit). The ohms scale thus appears to be reversed when compared with a voltage or current scale. The scale is also extremely non-linear and only low resistance values can be read with any degree of precision.

Check Point 7.2

An ohmmeter requires an internal battery in order to supply current to the external circuit on test. The amount of current flowing in the circuit is inversely proportional to the resistance of the circuit or component being measured.

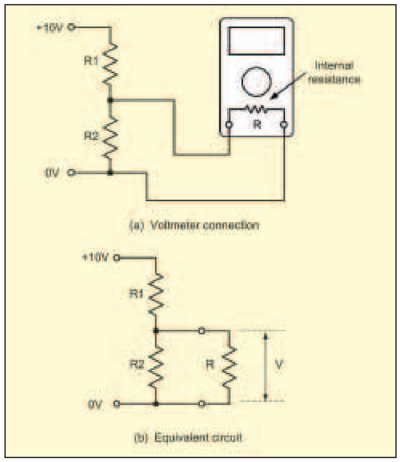


Fig.7.5. Effect of loading a circuit when making a measurement with a voltmeter

Loading

When a meter is used to make measurements on a circuit we need to ensure that conditions in the circuit are disturbed as little as possible. When using a voltmeter, for example, it is important not to remove too much current from the circuit. We mentioned this problem briefly in Part 2 and Fig.7.5 serves to illustrate the problem in a little more detail.

In Fig.7.5a we are attempting to measure the voltage across one of the resistors (R2 in this case) of a potential divider. The potential divider is fed from a DC supply of 10V. When the voltmeter is connected to the circuit, an additional resistance – the internal resistance of the meter (R) – appears in parallel with the lower resistor, R2. This reduces the resistance present in the lower half of the potential divider and the indicated voltage will consequently be less than the voltage without the meter present. Fig.7.5b shows the equivalent circuit when the voltmeter is connected.

The error introduced by connecting the voltmeter to the circuit will depend on the relative resistances (i.e. the size of R in comparison with R1 and R2). If R is very much larger than R1 and R2 the error will be small. If R is of a similar (or lesser) value than R1 and R2, the error will become very large. It's worth illustrating this by taking some representative values, as shown in Table 7.1.

From this it should be apparent that we should be using a voltmeter with as high an internal resistance as possible. With an ohms-per-volt rating of 20kΩ/V, the internal resistance of a reasonable quality analogue multirange meter can be as low as 50kΩ on the 2·5V range. This low value of internal resistance would be unimportant when making measurements on low-resistance circuits but with modern high-impedance electronic circuits the readings obtained with such instruments should be treated with some caution. With modern digital meters the input resistance is typically 10MΩ on the DC voltage ranges and so the readings obtained can be relied upon with more confidence.

Table 7.1

R1	R2	R	True voltage	Voltage indicated
1kΩ	1kΩ	100kΩ	5V	4·97V
10kΩ	10kΩ	100kΩ	5V	4·76V
100kΩ	100kΩ	100kΩ	5V	3·33V
1MΩ	1MΩ	100kΩ	5V	0·83V

Questions 7.1

Q7.1. In the circuit shown in Fig.7.5, R1 = 680kΩ and R2 = 220kΩ. If the voltage appearing across R2 is measured with an analogue meter having an ohms-per-volt rating of 20kΩ/V on the 2·5V range, determine the voltage that would actually be indicated on the meter.

Q7.2. In the circuit shown in Fig.7.5, R1 = 330kΩ and R2 = 470kΩ. If the voltage appearing across R2 is measured with a digital meter having a constant resistance on all ranges of 10MΩ, determine the voltage that would actually be indicated on the meter.

Check Point 7.3

When a voltmeter is connected to a circuit a small current is taken away from the circuit due to the internal resistance of the meter. In order to minimise the error it is necessary for the meter to have a resistance that is very much larger than the resistance (or impedance) of the circuit under investigation.

Measurements using an Analogue Multimeter

Despite the problems associated with loading, analogue multimeters do offer some important advantages over digital instruments. Arguably the most important of these is the ease of making adjustments – it is much easier to follow the movement of a pointer, up or down, than it is to watch a digital display that is constantly changing!

Most analogue multimeters provide a number of ranges and measurement functions that usually include:

- DC voltage (DC, V)
- DC current (DC, mA)
- AC voltage (AC, V)
- Resistance (OHM)
- Low resistance/Continuity test (BUZZ)
- Battery check (BAT)

How to make DC *voltage* measurements with a typical analogue multimeter is shown in Fig.7.6. The red and black test leads are connected to the "+" and "–" sockets respectively. In Fig.7.6, the range selector is set to DC V, 50V and the pointer is reading just 35 on the range that has 50 as its full-scale indication (note that there are three calibrated voltage scales with maximum indications of 10V, 50V and 250V respectively). The reading indicated is thus 35V.

The set up in Fig.7.7 shows how to make a DC *current* measurement with a typical analogue multimeter. Once again, the red and black test leads are connected to the "+" and "–" sockets respectively. The range selector is set to DC, 5mA. In Fig.7.7, the pointer is reading mid-way between 40 and 50 on the range that has 50 as its full-scale indication (but remember that we have selected the 5mA range). The actual reading indicated is thus 4·5mA.

Note that, in common with many simple multirange meters, both analogue and digital, the high current range (e.g. 10A) is not only selected using the range selector switch but a separate input connection must also be made. The reason for this is simply that the range switch and associated wiring is not designed to carry such a high current. Instead, the high-current shunt is terminated separately at its own "10A" socket.

How to make *resistance* measurements is illustrated in Fig.7.8. The red and black test leads are connected to the "+" and "-" sockets respectively. Before making any measurements it is absolutely essential to zero the meter. This is achieved by shorting the test leads together and adjusting the ZERO ADJ thumbwheel control until the meter reads full-scale (i.e., zero on the ohms scale). In Fig.7.8, the range selector is set to OHM, ×10. The pointer is reading 30 and the resistance indicated is thus 30 × 10 = 300Ω.

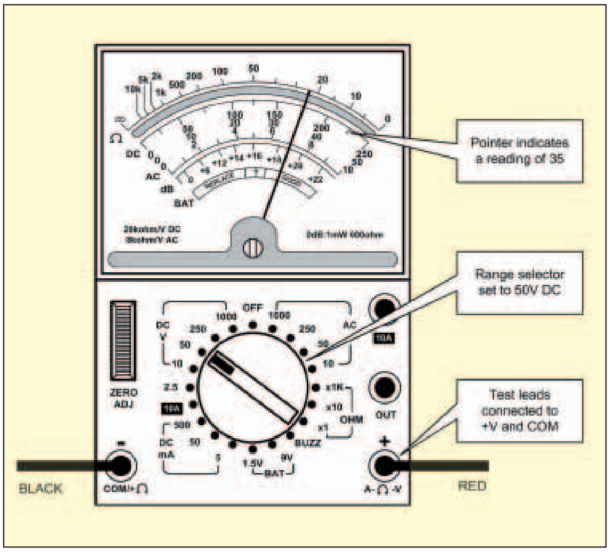


Fig.7.6. DC voltage measurement using an analogue multimeter

Measurements using a Digital Multimeter

Because the range selector can be used to change the position of the decimal point on the display, digital multimeters are easier to operate than their analogue counterparts. The functions available are typically:

- DC voltage (DC, V)
- DC current (DC, A)
- AC voltage (AC, V)
- AC current (AC, A)
- Resistance (OHM)
- Capacitance (CAP)
- Low resistance/Continuity test (buzzer)
- Transistor current gain (h_{FE})

How to make DC voltage measurements using a digital multirange meter is indicated in Fig.7.9. The red and black test leads

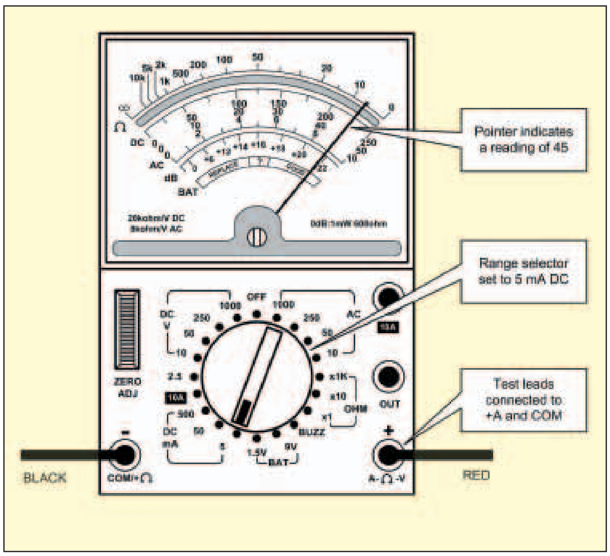


Fig.7.7. DC current measurement using an analogue multimeter

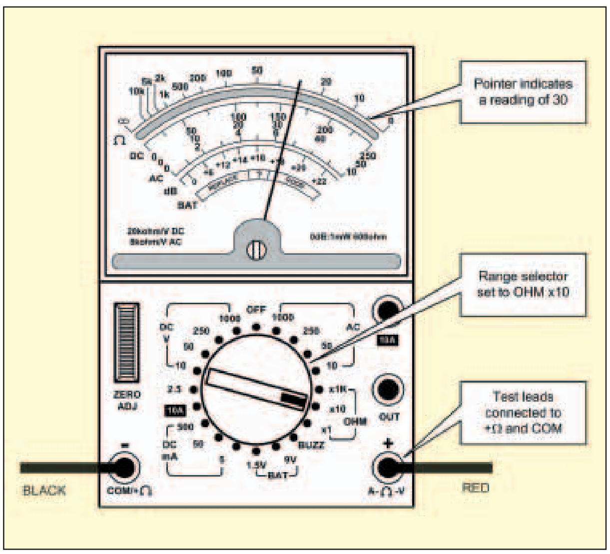


Fig.7.8. Resistance measurement using an analogue multimeter

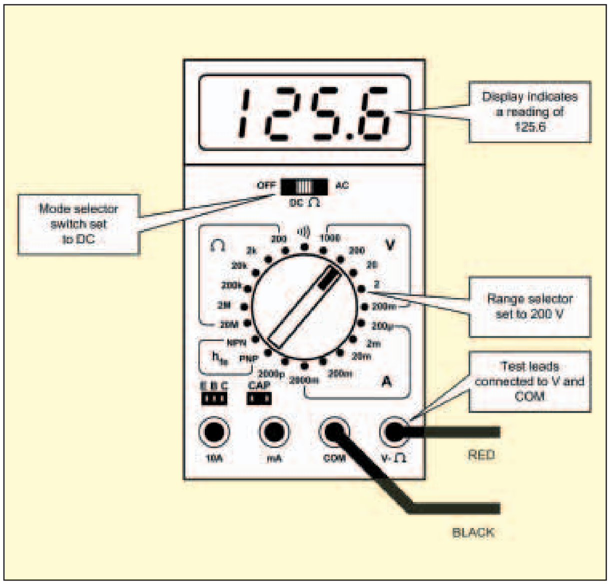


Fig.7.9. DC voltage measurement using a digital multimeter

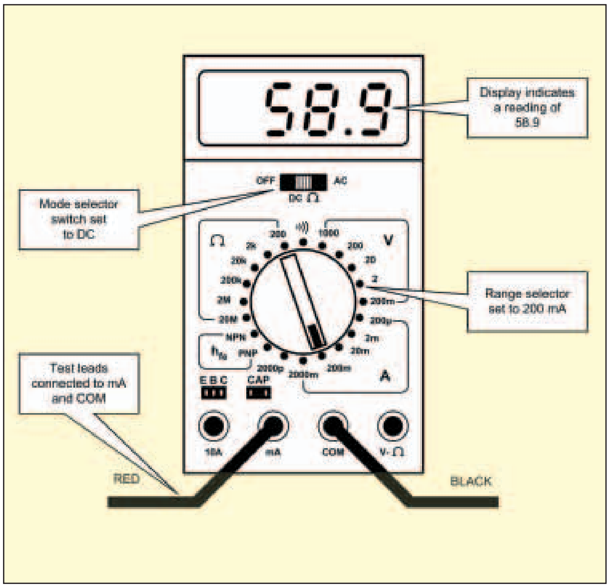


Fig.7.10. Current measurement using a digital multimeter

are connected to the "V-OHM" and "COM" sockets respectively. The mode switch and range selector is set to DC V, 200V, and the display indicates a reading of 125·6V.

How to make a DC current measurement is shown in Fig 7.10. Here, the red and black test leads are connected to the "mA" and "COM" sockets respectively. The mode switch and range selectors are set to DC, 200mA, and the display indicates a reading of 58·9mA.

The set up in Fig.7.11 shows how to make resistance measurements. As with voltage readings (7.9), the red and black test leads are connected to "V-OHM" and "COM" respectively. The mode switch and range selectors are set to OHM, 200Ω, and the meter indicates a reading of 35·8Ω. Note that is not necessary to "zero" the meter by shorting the test probes together before taking any measurements (as would be the case with an analogue meter).

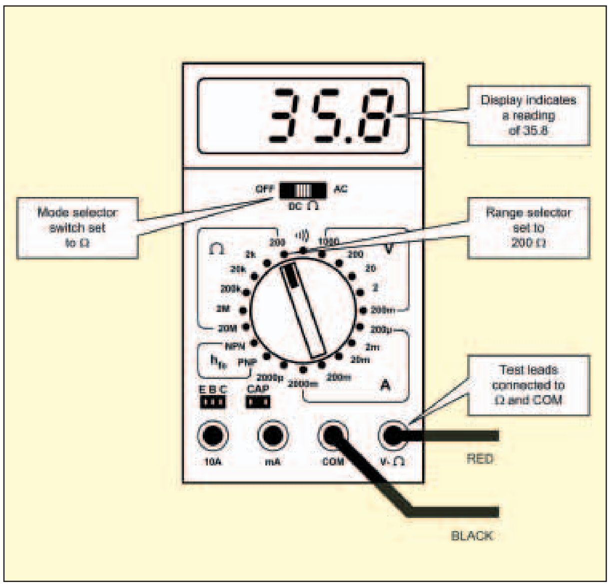


Fig.7.11. Resistance measurement using a digital multimeter

Measurements using an Oscilloscope

An oscilloscope can provide a great deal of information about what is going on in a circuit. In effect, it allows you to "see" into the circuit, displaying waveforms that correspond to the signals that are present. Conventional oscilloscopes (which are items of standard electronic test equipment) use cathode ray tube (CRT) displays but these are being increasingly replaced by digital instruments with liquid crystal displays (LCD). In addition, virtual oscilloscopes are available that use a digital signal processing interface (a high-speed analogue-to-digital converter) connected to a PC using an adapter card, parallel port, or USB port.

The display provided by a conventional oscilloscope fitted with a CRT has a typical screen area of 8cm × 10cm. The screen is fitted with a ruled scale (or graticule) that may either be integral with the tube face or a separate translucent sheet. The graticule is usually ruled with a one centimetre grid to which further bold lines may be added to mark the major axes on the central viewing area.

Accurate voltage and time measurements may be made with reference to the graticule, applying a scale factor derived from the appropriate range switch (voltage/cm and time/cm respectively). Comparable waveform displays are provided by virtual instruments but with the added advantage that waveforms can be digitally stored and recalled for later analysis.

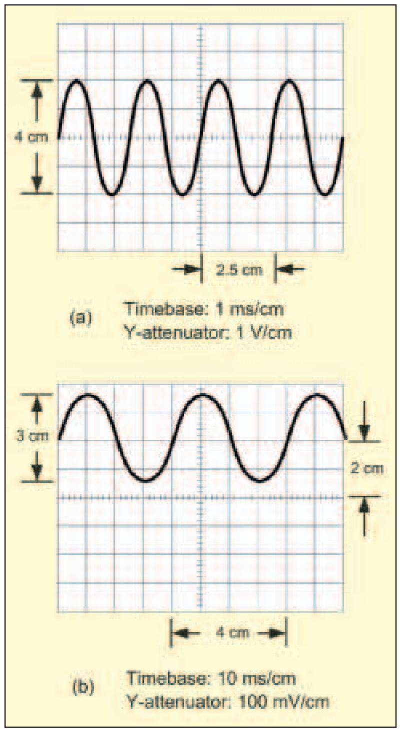


Fig.7.12. See Examples 7.3 and 7.4

A word of caution is appropriate at this stage, however. Before taking meaningful measurements from an oscilloscope screen it is absolutely essential to ensure that the front panel variable controls are set in the calibrate (CAL) position. Results will almost certainly be inaccurate if this is not the case! The use of the graticule is illustrated in the next two examples:

Example 7.3

An oscilloscope screen is shown in Fig.7.12a. The fine graticule markings are shown every 2mm along the central vertical and horizontal axes with the main grid

Table 7.2. Some of an osciloscope's most important controls and adjustments

Control	Function or adjustment
Focus	Provides a correctly focused display on the CRT screen
Intensity	Adjusts the brightness of the display
Astigmatism	Provides a uniformly defined display over the entire screen area and in both *X* and *Y*-directions. Normally used in conjunction with the focus and intensity controls
Timebase (time/cm)	Adjusts the timebase range and sets the horizontal time scale. Usually this control takes the form of a multi-position rotary switch and an additional continuously variable control is often provided. The "CAL" position is usually at one, or other, extreme setting of this control
Stability	Adjusts the timebase so that a stable displayed waveform is obtained
Trigger level	Selects the particular level on the triggering signal at which the timebase sweep commences
Trigger slope	This usually takes the form of a switch that determines whether triggering occurs on the positive or negative going edge of the triggering signal
Trigger source	This switch allows selection of one of several waveforms for use as the timebase trigger. The options usually include an internal signal derived from the vertical amplifier, a 50Hz signal derived from the supply mains, and a signal which may be applied to an "External Trigger" input
Vertical attenuator (V/cm)	Adjusts the magnitude of the signal attenuator (V/cm) displayed and sets the vertical voltage scale. This control is invariably a multi-position rotary switch. However, an additional variable gain control is sometimes also provided. Often this control is concentric with the main control and the "CAL" position is usually at one, or other, extreme setting of the control
AC-DC-Ground	Normally an oscilloscope employs DC coupling throughout the vertical amplifier; hence a shift along the vertical axis will occur whenever a direct voltage is present at the input. When investigating waveforms in a circuit one often encounters AC superimposed on DC levels; the latter may be removed by inserting a capacitor in series with the signal. With the AC-DC-Ground switch in the AC position a capacitor is inserted in the input lead, whereas in the DC position the capacitor is shorted. If Ground is selected, the vertical input is taken to common (0V) and the oscilloscope input is left floating. This last facility is useful in allowing the accurate positioning of the vertical position control along the central axis. The switch may then be set to DC and the magnitude of any DC level present at the input may be easily measured by examining the shift along the vertical axis.
Chopped-alternate	This control, which is only used in dual-beam oscilloscopes, provides selection of the beam splitting mode. In the chopped position, the trace displays a small portion of one vertical channel waveform followed by an equally small portion of the other. The traces are, in effect, sampled at a relatively fast rate, the result being two apparently continuous displays. In the alternate position, a complete horizontal sweep is devoted to each channel alternately
Horizontal position	Positions the display along the horizontal axis of the CRT
Vertical position	Positions the display along the vertical axis of the CRT

repeating every 1cm. The oscilloscope is operated with all relevant controls in the "CAL" position. The timebase (horizontal deflection) is switched to the 1ms/cm range and the vertical attenuator (vertical deflection) is switched to the 1V/cm range.

The overall height of the trace is 4cm and thus the peak-to-peak voltage is 4 × 1V = 4V. Similarly, the time for one complete cycle (period) is 2·5 × 1ms = 2·5ms (corresponding to a frequency, calculated using f = 1/t, of 400Hz). One further important piece of information is the shape of the waveform that, in this case, is sinusoidal.

Example 7.4

Another oscilloscope screen is shown in Fig.7.12b. This screen uses the same scale markings as before. The timebase (horizontal deflection) is switched to the 10ms/cm range and the vertical attenuator (vertical deflection) is switched to the 100mV/cm range (once again, the relevant variable controls have been set to the "CAL" position).

The overall height of the trace is 3cm and so the peak-to-peak voltage is 3 × 100mV = 0·3V. Similarly, the time for one complete cycle (period) is 4 × 10ms = 40ms (corresponding to a frequency, calculated using f = 1/t, of 25Hz). The waveform is, once again sinusoidal. However, it's important to note that the display has been shifted upwards indicating a DC offset from zero (in other words, unlike the waveform shown in Example 7.2, there is a DC level present on the waveform).

The DC level is displayed by using the oscilloscope with its input set to "DC" rather than "AC" (if "AC" is used the sinusoidal waveform will swing symmetrically about 0V). In Fig.12b the displacement of the waveform (above 0V) is 2cm, which is

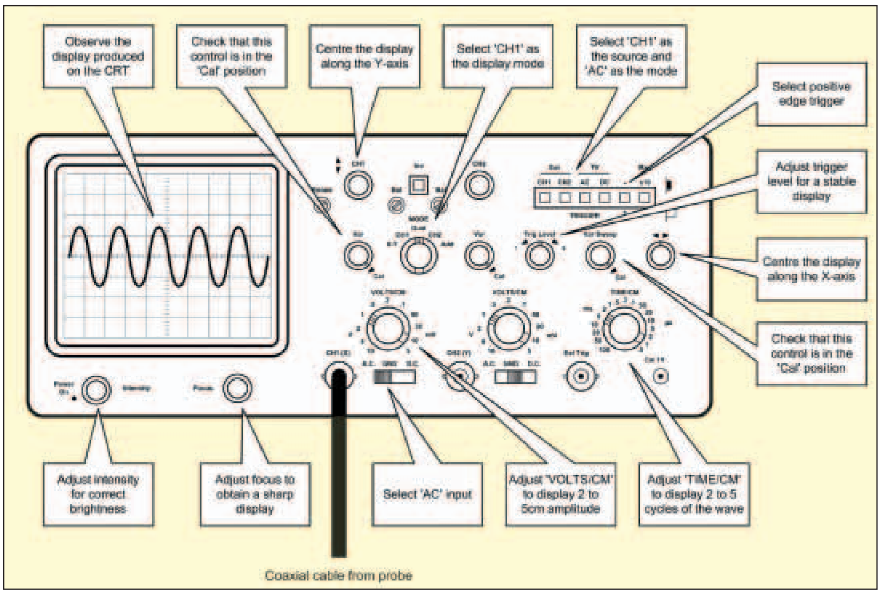


Fig.7.13. Controls and adjustments for displaying a simple repetitive sinusoidal waveform

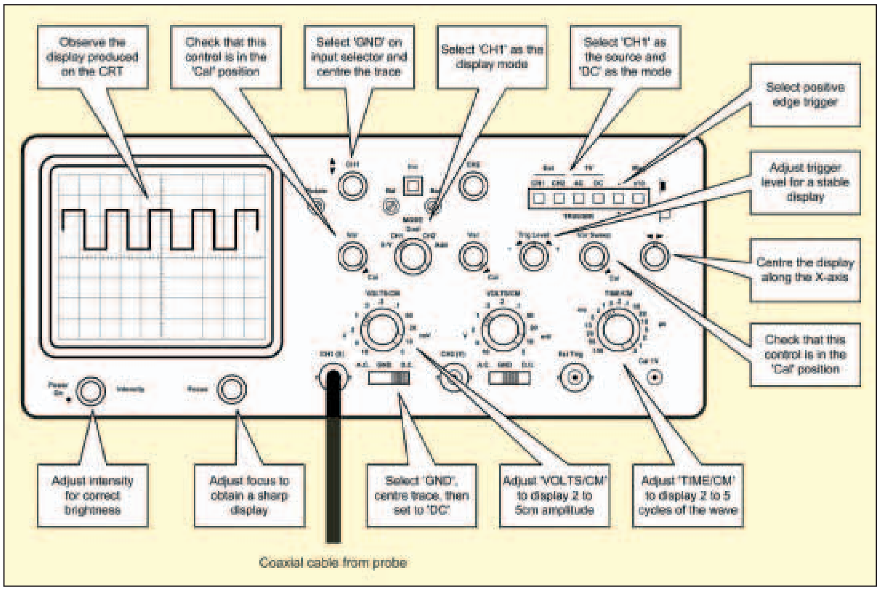


Fig.7.14. Controls and adjustments for displaying a simple repetitive square waveform in which a DC level is present

equivalent to 2 × 100mV = 0·2V. Hence the waveform has a peak-to-peak voltage of 0·3V superimposed on a DC level of 0·2V.

At first sight, the controls provided by an oscilloscope can appear somewhat baffling. However, with a little practice it is relatively easy to carry out basic measurements of voltage and time as well as general waveform investigation. Some of the most important controls and adjustments are summarised in Table 7.2.

The controls and adjustments for displaying a simple repetitive sine and square waveforms using a conventional bench test oscilloscope are shown in Fig.7.13 and Fig.7.14. In order to display the sinusoidal waveform (Fig.7.13), the signal is connected to the Channel 1 input (with "AC" input selected) and the Mode switch in the Channel 1 position. "Channel 1" must be selected as the trigger source and the trigger level control adjusted for a stable display. Where accurate measurements are required it is essential to ensure that the "CAL" position is selected for both the variable gain and time controls.

The procedure for displaying a repetitive square waveform is shown in Fig.7.14. Once again, the signal is connected to the Channel 1 input (but this time with "DC" input selected) and the Mode switch in the Channel 1 position. "Channel 1" must be selected as the trigger source and the trigger level control adjusted for a stable display (which can be triggered on the positive or negative going edge of the waveform according to the setting of the trigger polarity button).

Any DC level present on the input can be measured from the offset produced on the Y-axis. To do this, you must first select "GND" on the input selector then centre the trace along the Y-axis before switching to "DC" and noting how far up or down the trace moves (above or below 0V). This may sound a little difficult but it is actually quite easy to do! The same technique can be used for measuring any DC offset present on a sinusoidal signal.

Distortion Checking

Oscilloscopes are frequently used to investigate distortion in amplifiers and other electronic systems. Different forms of distortion have a different effect on a waveform and thus it is possible to determine which type of distortion is present.

A "pure" sine wave is used as an input signal and the output is then displayed on the oscilloscope. Fig.7.15 shows waveforms that correspond to the most common forms of distortion.

Frequency Response Checking

An oscilloscope can also be used to provide a rapid assessment of the frequency

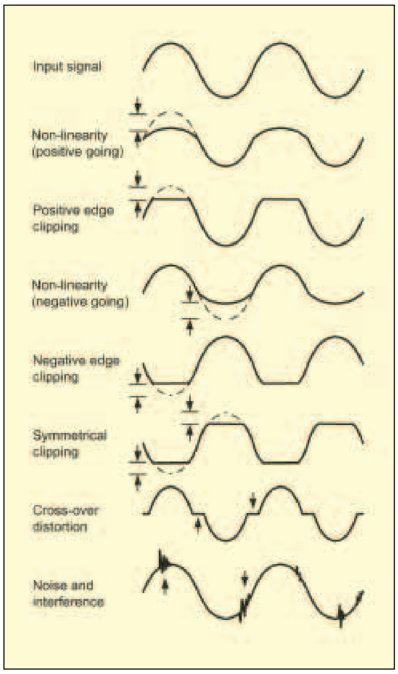


Fig.7.15. Typical waveform displays with various types of distortion present

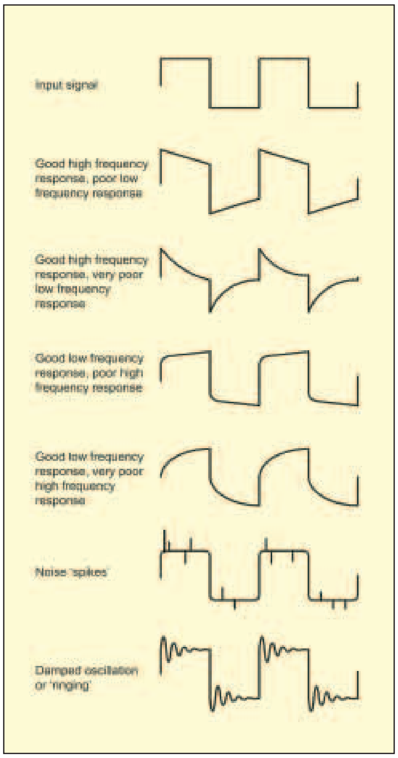


Fig.7.16. Typical waveforms produced during square wave tests

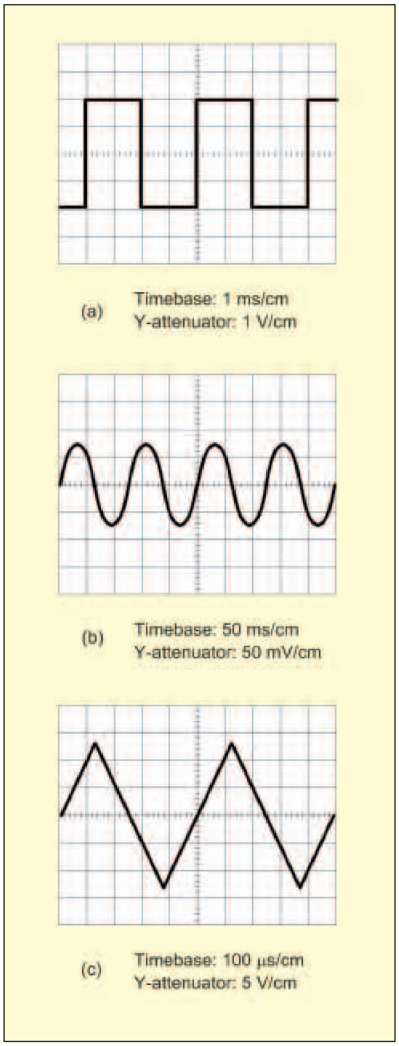


Fig.7.17. See Questions 7.2

Check Point 7.4

When sine and square wave signals are used as inputs, waveforms displayed on an oscilloscope provide us with a means of respectively assessing the distortion and frequency response produced by a circuit.

Questions 7.2

Fig.7.17 shows three different waveforms displayed on an oscilloscope screen. For each waveform determine:

(a) the peak-to-peak voltage
(b) the periodic time
(c) the frequency
(d) the type of waveform
(e) whether or not a DC level is present.

response of an amplifier or other electronic system. Instead of using a sinewave as an input signal a square wave input is used.

Different frequency response produces a different effect on a waveform and thus it is possible to assess whether the frequency response is good or poor (a perfect square wave output corresponds to a perfect frequency response). Fig.7.16 shows waveforms that correspond to different frequency response characteristics.

Practical Investigation 7.1

Objective: To use virtual test and measuring instruments to investigate waveforms in simple C-R integrating circuit.

Components and materials: Breadboard, PC with sound card and Wave Tools software (see below), audio connecting leads (see below), 100kΩ resistor, capacitors of 22nF, 47nF, 100nF, 220nF and 470nF, connecting wire.

Circuit diagram: See Fig.7.18

Wiring diagram: See Fig.7.19

Procedure: The required breadboard wiring is shown in Table 7.3.

1. Download the Wave Tools software from **www.miketooley.info** (click on the Downloads tab). The software consists of a number of files stored in a single compressed folder called **4in1tool**. Transfer the folder to your PC and store it in a folder of your choice (for example, **C:\wavetools**). Unzip the folder so that all of the files are present in the same directory – see Fig.7.20. If desired, create a shortcut on your desktop to the executable files:

- scope.exe (a virtual oscilloscope)
- meter.exe (a virtual a.c. voltmeter)
- analyser.exe (a virtual spectrum analyser)
- sig-gen.exe (a virtual signal generator)

2. The Wave Tools software requires a PC with a sound card that can record and play back digital audio simultaneously (most modern sound cards will do this). Before using the Wave Tools software for the first time you may need to adjust your sound card settings so that the headphone socket (usually a 3·5mm jack connector) is configured for output and the line socket (invariably another 3·5mm jack connector) is configured for input. Some

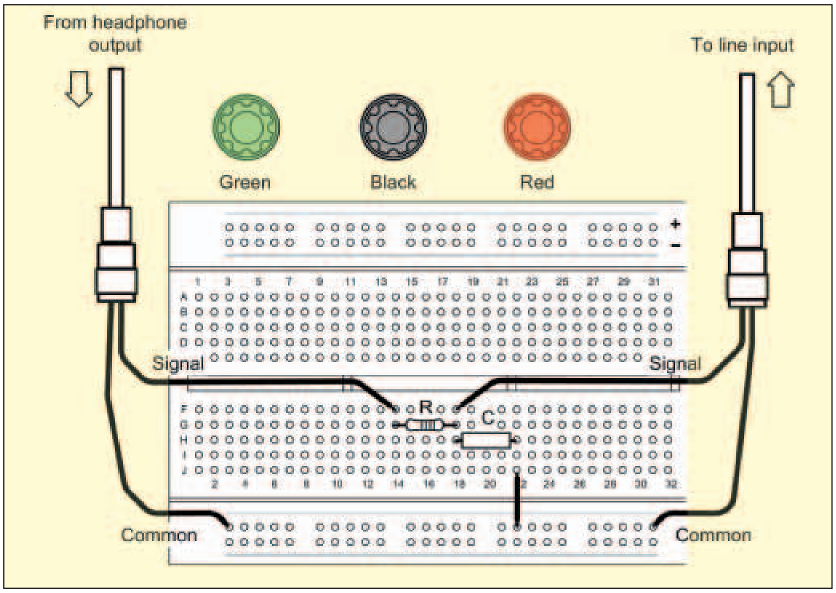


Fig.7.19. Wiring diagram for Practical Investigation 7.1

Table 7.3. Breadboard wiring required for Investigation 7.1.

Step	Connection, link or component	From	To
1	PC headphone socket (output)	Signal	F14
2	PC headphone socket (output)	Common	Common 3
3	PC line input socket (input)	Signal	F18
4	PC line input socket (input)	Common	Common 31
5	R 100kΩ	G14	G18
6	C 22nF	H18	H22
7	Link	J22	Common 22

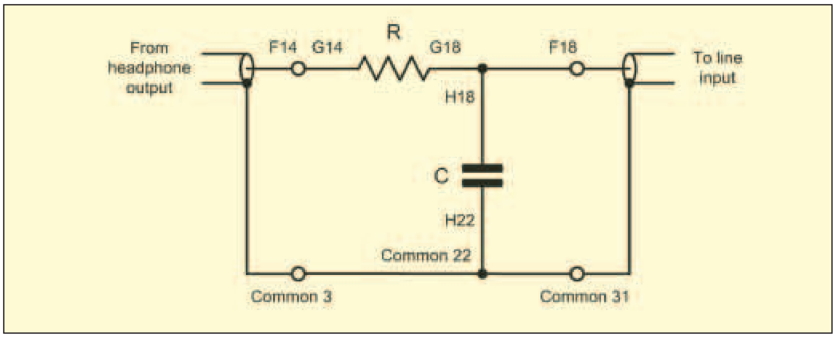


Fig.7.18. Circuit diagram for Practical Investigation 7.1

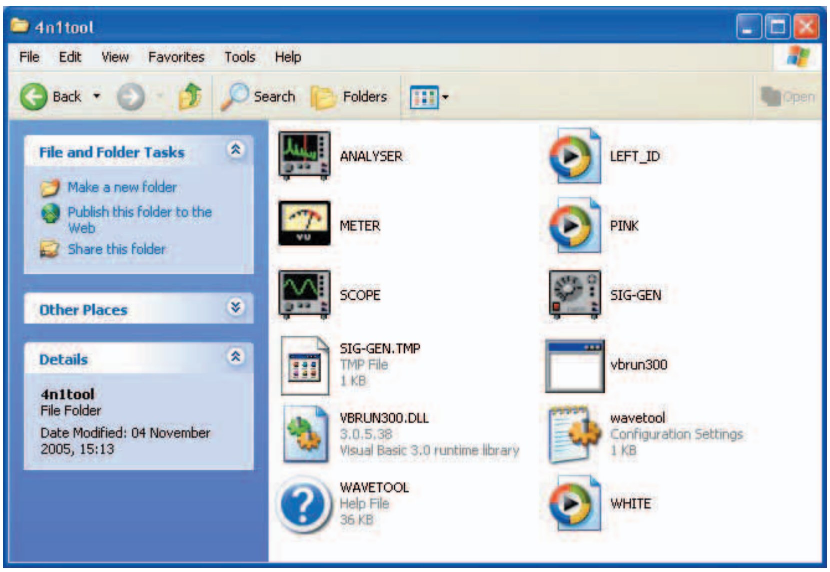


Fig.7.20. The various Wave Tools are located in the 4in1tool folder

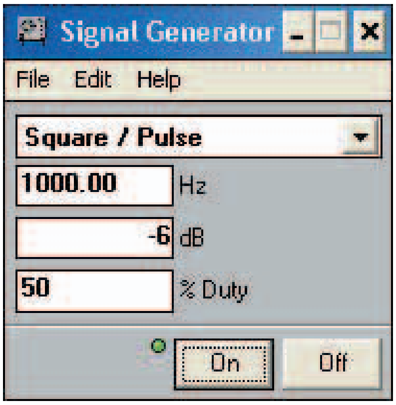


Fig.7.21. Setting the signal generator tool to produce a 1kHz square output

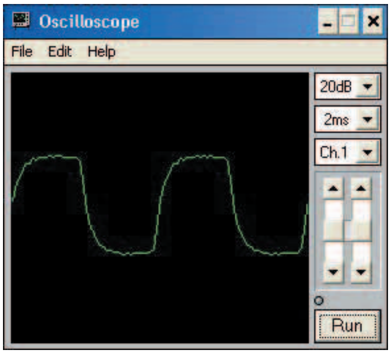


Fig.7.22. Oscilloscope tool settings required to display the output of the integrating circuit. Note that the leading edge of the square wave has been "rounded" due to the charging time constant of the C-R circuit

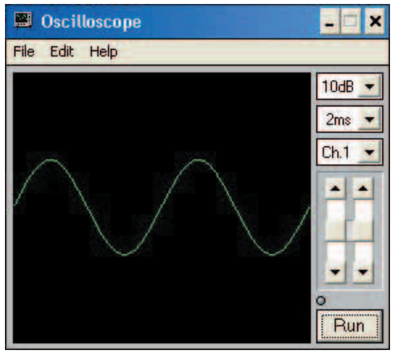


Fig.7.23. The 1kHz output of the signal generator displayed using the virtual oscilloscope tool

experimentation may be required with the settings and you should refer to your sound card manual or help file for further information.

3. Connect the headphone output from your PC via a suitable audio lead (e.g. a lead fitted with a 3·5mm jack plug at one end and a phono socket at the other) to the input of the integrating circuit (two short lengths of insulated wire connected to a phono plug can be useful here, as shown in Fig.7.19).

4. Connect the line input to your PC via another audio lead (e.g. another lead fitted with a 3·5 mm jack at one end and a phono socket at the other) to the output of the integrating circuit (once again, two short lengths of insulated wire connected to a phono plug can be useful here, as shown in Fig. 7.19).

5. Click on the signal generator icon to start the signal generator tool and set the output to square/pulse, 1000Hz, -6dB, and 50% duty cycle as shown in Fig.7.21. Finally, click on the "On" button to generate the waveform with the parameters that you have just entered.

6. Click on the oscilloscope icon to start the oscilloscope tool and set the controls to 20dB (vertical attenuator), 2ms (timebase), and Channel 1 (you may also need to adjust the slider control (vertical position) in order to obtain a trace that is vertically centred on the display). Finally, click on "Run" in order to display the waveform (you can click this button a second time in order to "freeze" the display). The waveform displayed should now be similar to that shown in Fig.7.22 (if this display is not obtained you should check your sound card settings, audio leads and connectors).

7. Repeat step 6 with different values for C (47nF, 100nF, 220nF and 470nF). Display the waveform for each combination (you may need to increase the vertical gain setting in order to increase the size of the display).

Conclusion: Comment on the shape of each waveform. Is this what you would expect? What effect does the time constant have on the output waveform from the integrating circuit?

Practical Investigation 7.2

Objective: To use virtual test and measuring instruments to investigate the frequency spectrum of different waveforms.

Components and materials: As for Practical Investigation 7.1

Circuit and wiring diagrams: As for Practical Investigation 7.1 but with C removed and R replaced by a link.

Procedure:

1. Ensure that the Wave Tools software is installed and audio leads connected as described in Practical Investigation 7.1.

2. Click on the signal generator icon to start the signal generator tool and set the output to sine, 1000Hz, and -6dB, then click on the "On" button to generate the waveform with the parameters that you have just entered.

3. Click on the oscilloscope icon to start the oscilloscope tool and set the controls to 10dB (vertical attenuator), 2ms (timebase), and Channel 1 (you may also need to adjust the slider control (vertical position) in order to obtain a trace that is vertically centred on the display). Click on "Run" in order to display the waveform (you can click this button a second time in order to "freeze" the display). The waveform displayed should now be similar to that shown in Fig.7.23.

4. Click on the analyser icon to start the spectrum analyser. This tool displays the amplitude of the signal shown against frequency (rather than time). The result is a frequency spectrum. For a pure signal (i.e. a sine wave) there should be only one signal frequency component present, as shown in Fig.7.24.

5. Change the signal generator settings and repeat steps 2 to 4, first for square and then for triangular waves. Observe the waveforms using the oscilloscope tool and the frequency spectra using the analyser tool.

Conclusion: Comment on the frequency spectra produced. What does this tell you about the signal components present in square and triangular waves?

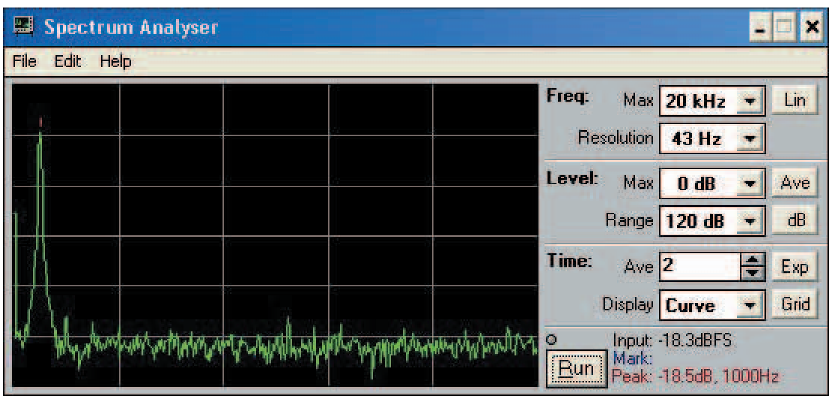


Fig.7.24. Spectrum analyser tool settings required to display the frequency spectrum of the 1kHz sine wave shown in Fig.7.23. Note the single frequency that is present (1kHz) and the "noise" floor that is evenly distributed in frequency

Next Month

In Part 8, next month, we shall be introducing logic gates and digital integrated circuits. In the meantime you might like to see how you get on with our on-line quiz for Part 7. You will find this at: **www.miketooley.info/teach-in/quiz7.htm**.

Answers To Questions

Q7.1 1. 0·57V 2. 5·76V

Q7.2 1. (a)4V (b)150mV (c)25V
2. (a)4ms (b)125ms (c)500μs
3. (a)250Hz (b)8Hz (c)2kHz
4. (a) square (b) sine (c) triangle
5. (a) no (b) no (c) no

PRACTICALLY SPEAKING

Robert Penfold looks at the Techniques of Actually Doing It!

I AM not going to look back through over 400 issues of *EPE* to check this point, but I am reasonably confident that there have only been one or two projects that do not use any capacitors. Most projects use several of them, and in some designs they outnumber the resistors.

Capacitors have tended to be a bit problematic in the past due to the large number of different types. If anything, the situation has become more difficult in recent years. New types have appeared, along with numerous variations on existing varieties.

Even "old hands" at project building can find it a bit difficult to keep up-to-date, and there is plenty of scope for beginners to make mistakes. With mid-range values you could well find 10 or 20 different components of the required value. Determining which one or ones are suitable for your particular application can be a bit confusing.

Getting Physical

There are generally three factors that have to be taken into account when selecting a capacitor. These are the electrical characteristics, the type of construction used, and the physical characteristics.

Do not be tempted to overlook the last one, because modern circuit boards tend to be designed to take capacitors of a certain physical size and lead spacing. There is no chance of producing a neat circuit board if you should obtain some capacitors that are much too big to fit the available space on the board. While it might be possible to find a way of squeezing them in, oversize capacitors might not be usable at all.

The situation is not much better with some capacitors that are too small. The types that have tubular bodies and long leads should fit into place without any difficulty. Capacitors of this type are usually referred to as "axial" capacitors (see Fig.1 top and middle).

Printed circuit (PC) mounting capacitors are far less accommodating, and these have short leads that are effectively printed circuit pins (Fig.1 bottom). These leave little room for manoeuvre, and with some types there is a likelihood that the leads will break off if you try bending them outward to fit a wider lead spacing. In general, the types that have a plastic case are much tougher than the uncased variety.

There are ways around the problem of leads that do not reach the holes in the board. You can solder short extension wires to the board and then connect the capacitors to them, but this will not give particularly neat or strong results. This type of thing is fine as a temporary fix until a more suitable component can be obtained, but should not be used as a normal construction method.

These days, and perhaps not surprisingly, most printed circuit boards are designed to accommodate printed circuit mounting capacitors. The correct lead spacing for these should be stated in the components list, but if in any doubt it can be checked by making measurements on the relevant diagram or the board itself. Using components of the wrong lead spacing has to be regarded as doing things the hard way, since there will almost certainly be plenty of components having the right spacing.

Table 1

Farad (F)	Microfarad (µF)	Nanofarad (nF)	Picofarad (pF)
1 Farad =	1000000	1000000000	1000000000000
0.000001 Farads =	1	1000	1000000
0.000000001 Farads =	0.001	1	1000
0.000000000001 Farads =	0.000001	0.001	1

Materialism

A capacitor is a very simple component that is basically just two metal plates separated by a thin insulating layer. In practice there is a slight problem in that the plates need to be fairly large in order to provide even low values of capacitance. The standard solution is to have the plates in the form of long but narrow strips of metal foil. Also, an extra layer of insulation is added on one of the strips. The strips, complete with the foil insulation, are then rolled up to produce an axial component. A sort of folding and rolling process is used to produce box shaped printed circuit mounting components.

The insulating material is called the *dielectric*, and the perfect dielectric has yet to be discovered. Consequently, various materials are used as the dielectric, with each one providing characteristics that are well suited to particular applications.

It is this plethora of common dielectrics that is responsible for the huge variety of capacitors on offer in the larger component catalogues. In general, the names given to the various types of capacitor (Mylar, polycarbonate, polyester, etc.) are the materials used as the dielectric.

Unfortunately, you cannot simply ignore this aspect of things when ordering capacitors. A component that is perfect in all other respects but uses the wrong type of dielectric will not necessarily produce acceptable results. In an extreme case it could result in the project failing to work at all, but in most instances it will result in poor results and (or) reliability.

For example, some capacitors are designed to work well at very high operating frequencies. Substituting a type that has mediocre performance at high frequencies could result in the circuit becoming unstable and having odd traits, lacking sensitivity, providing too little output, or whatever. The project could work perfectly or it might have all sorts of problems. You have to avoid potential problems by ensuring that you use a suitable type.

The components list will probably specify a particular type for every capacitor that is listed. The designer will usually specify a low-cost type when the exact characteristics are not important. This will typically be a ceramic component for low values and a polyester type at higher values.

Using a higher quality type is perfectly all right provided it has the right physical characteristics, but this could substantially increase the cost of a project. It could be worthwhile if there are supply difficulties with lower cost alternatives, but using "over the top" components should otherwise be avoided.

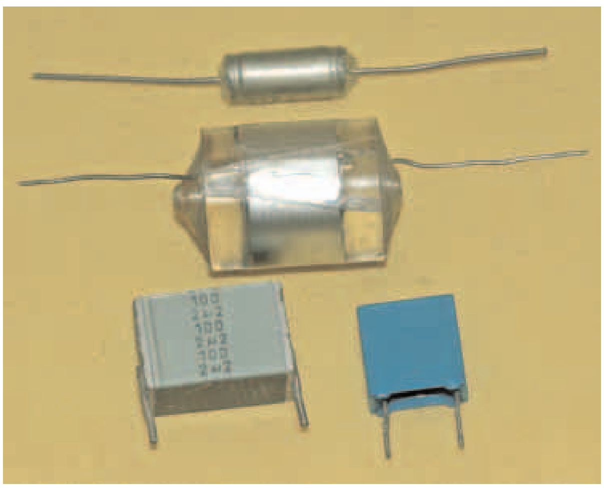


Fig.1. Axial lead capacitors (top and middle) are used relatively little in modern projects. PC capacitors (bottom) are now the norm

Values

The basic unit of capacitance is the *Farad*, but one farad is a very large amount of capacitance. The largest capacitor you ever use is unlikely to be more than about a thousandth of a farad, and the smallest will be a few millionths of a millionth of a farad.

Real-world capacitors have their values expressed in *microfarads* (µF), *nanofarads* (nF), and *picofarads* (pF). Table 1 shows the relationship between these units and the farad. What it boils down to is that 1 nanofarad = 1000 picofarads, and one

microfarad equals 1000 nanofarads and 1000000 picofarads.

A capacitor that has a value of (say) 100 nanofarads could also have its value given as 0·1 microfarads, or even 100000 picofarads. You will sometimes find values given in one form in a components list and another in a components catalogue, so you have to get used to using some quick mental arithmetic to convert from one to the other.

At one time it was quite common for capacitors to have their values marked using colour codes that were based on the system used for resistors. Capacitor colour coding has gradually died out though. These days the values are written on the components, although often in a rather cryptic form. This subject was covered in the *Practically Speaking* article in the September 2005 issue of *EPE* and will not be considered further here.

Voltage

Capacitors have a maximum voltage rating, but this is usually of little practical importance when selecting suitable components. Most capacitors can operate properly at 100 volts or more. A few types, such as some ceramic capacitors, have lower maximum voltage ratings. However, with voltage ratings that are generally 25V or more, they are still perfectly adequate for most of today's low voltage circuits.

Of course, a few projects do operate with relatively high voltages, and the voltage ratings of certain capacitors will then be more critical. In such cases you have to be more careful with your component choice, making sure that the selected components have voltage ratings equal to or higher than those specified in the components list. Before ordering components that have higher voltages than those specified in the components list, make sure that they are not physically too large.

There might be an occasional project which requires a special capacitor that is capable of working at very high voltages, or continuously with high alternating voltages (AC). There are other "specials" that provide excellent stability, high accuracy, etc. The components list and (or) the text of the article concerned should give full details when a capacitor that is out of the ordinary is required.

Tolerance

The tolerance rating of a capacitor is simply the maximum amount that its real value will deviate from its marked value. For example, a 100 nanofarad component that has a 10 percent tolerance rating will have an actual value that is in the range 90 to 110 nanofarads. Most capacitors have fairly high tolerance figures of about 10 or 20 percent, but high quality one or two percent types are also available.

In many applications the tolerance rating is not of any practical importance, and it is not specified in the components list. The maximum acceptable tolerance will be specified in cases where it is of importance, and it is then essential to use a component of at least the specified accuracy.

Electrolytic Capacitors

Producing capacitors having values of more than about one microfarad (1μF) using conventional methods tends to produce huge and expensive components. The normal solution is the *electrolytic* capacitor, which is constructed in much the same way as a conventional capacitor.

However, the dielectric is in the form of a porous material that contains a liquid or jelly-like electrolyte. This enables very high value components that are physically small to be produced, but electrolytic capacitors have some major drawbacks.

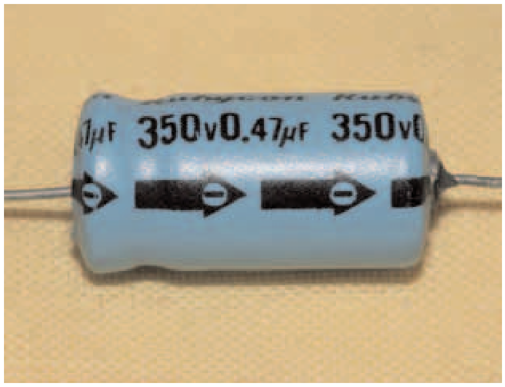


Fig.2. An indentation around the body indicates the positive end of an axial electrolytic capacitor. The "−" and (or) "+" legends are normally included as well

Get It Right

One is that an electrolytic capacitor will only work properly if it is fed with a voltage of the *correct polarity*. This is not a major problem from the design point of view, since this voltage will already be present in most applications for these components. From the practical standpoint, it means that you have to be careful to connect electrolytic capacitors with the correct polarity when constructing projects. Getting it wrong will almost certainly prevent the project from working, and with something like a supply decoupling or smoothing capacitor it could be extremely dangerous.

A high current can flow if an electrolytic capacitor is connected the wrong way around, and even with a small battery powered project this could result in the capacitor literally going out with a bang! Be especially careful with the larger types and those that operate at relatively high voltages.

Polarity Sensitive

The polarity of a capacitor is normally marked with "−" and (or) "+" signs on the body of the component. The current convention seems to be for only the "−" sign to be included, particularly with components of the printed circuit mounting variety. The convention is for axial electrolytic capacitors to have the positive (+) leadout wire indicated by an indentation around the body at the appropriate end of the component (see Fig.2). This makes it possible to see the polarity of the component at a glance. The polarity markings are normally present as well, and with some modern components these are the only method used to indicate the polarity.

Printed circuit mounting electrolytic capacitors usually have an indentation at the end of the body from which the leadout wires emanate. This is presumably produced as a normal part of the manufacturing process and it is of no significance.

With some printed circuit electrolytic capacitors the markings are a tad confusing, but it is still easy to determine the correct polarity. The negative (−) lead is usually shorter than the positive (+) one (Fig.3).

Danger – Low Voltage

Electrolytic capacitors have the advantage of combining high values with small physical size, but this probably represents the complete list of their good points. Their leakage currents are relatively high, as are their tolerance ratings. Their values tend to change significantly with temperature and the passage of time. This has resulted in various improved electrolytic components being produced, as well as higher quality alternatives such as *tantalum* types. It is essential to use a high quality component whenever it is called for in the components list.

Electrolytic and other very high value capacitors tend to have relatively low maximum operating voltages. With the highest values the maximum working voltage can be as little as a few volts.

Consequently, it is necessary to take more care when ordering these components, making sure that you obtain components having voltage ratings that are equal to or higher than the ones quoted in the components lists. Even slightly exceeding the voltage rating of a large electrolytic capacitor tends to have the same explosive result as using it with the wrong polarity.

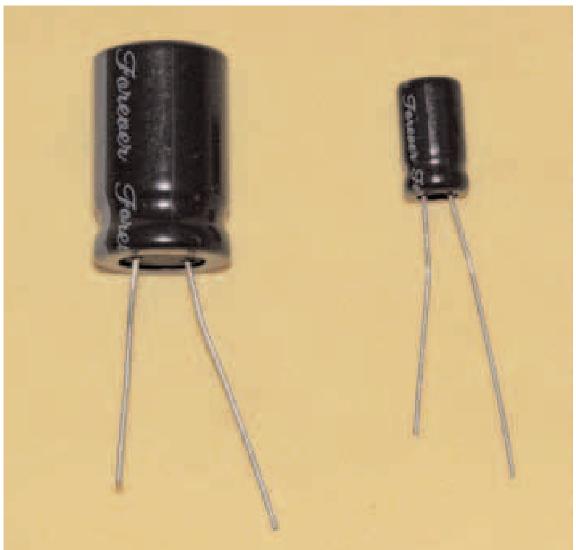


Fig.3. PC electrolytic capacitors usually have one lead shorter than the other. The shorter lead is the negative (−) one

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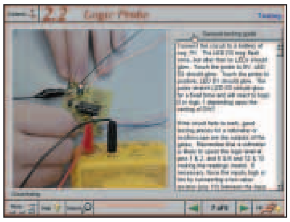
ELECTRONICS CD-ROMS

ELECTRONICS PROJECTS

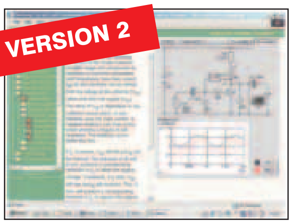


Logic Probe testing

Electronic Projects is split into two main sections: **Building Electronic Projects** contains comprehensive information about the components, tools and techniques used in developing projects from initial concept through to final circuit board production. Extensive use is made of video presentations showing soldering and construction techniques. The second section contains a set of ten projects for students to build, ranging from simple sensor circuits through to power amplifiers. A shareware version of Matrix's CADPACK **schematic capture**, **circuit simulation** and **p.c.b. design** software is included.
The projects on the CD-ROM are: Logic Probe; Light, Heat and Moisture Sensor; NE555 Timer; Egg Timer; Dice Machine; Bike Alarm; Stereo Mixer; Power Amplifier; Sound Activated Switch; Reaction Tester. Full parts lists, schematics and p.c.b. layouts are included on the CD-ROM.

ELECTRONIC CIRCUITS & COMPONENTS V2.0

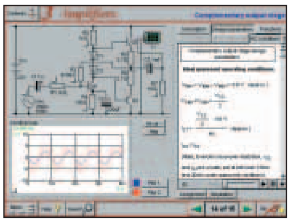
VERSION 2



Circuit simulation screen

Provides an introduction to the principles and application of the most common types of electronic components and shows how they are used to form complete circuits. The virtual laboratories, worked examples and pre-designed circuits allow students to learn, experiment and check their understanding. Version 2 has been considerably expanded in almost every area following a review of major syllabuses (GCSE, GNVQ, A level and HNC). It also contains both European and American circuit symbols. Sections include: ***Fundamentals:*** units & multiples, electricity, electric circuits, alternating circuits. ***Passive Components:*** resistors, capacitors, inductors, transformers. ***Semiconductors:*** diodes, transistors, op.amps, logic gates. ***Passive Circuits. Active Circuits.*** *The Parts Gallery* will help students to recognise common electronic components and their corresponding symbols in circuit diagrams. Included in the Institutional Versions are multiple choice questions, exam style questions, fault finding virtual laboratories and investigations/worksheets.

ANALOGUE ELECTRONICS

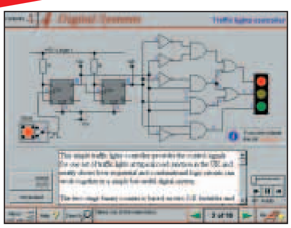


Complimentary output stage

Analogue Electronics is a complete learning resource for this most difficult branch of electronics. The CD-ROM includes a host of virtual laboratories, animations, diagrams, photographs and text as well as a SPICE electronic circuit simulator with over 50 pre-designed circuits.
Sections on the CD-ROM include: **Fundamentals** – Analogue Signals (5 sections),Transistors (4 sections), Waveshaping Circuits (6 sections). **Op.Amps** – 17 sections covering everything from Symbols and Signal Connections to Differentiators. **Amplifiers** – Single Stage Amplifiers (8 sections), Multi-stage Amplifiers (3 sections). **Filters** – Passive Filters (10 sections), Phase Shifting Networks (4 sections), Active Filters (6 sections). **Oscillators** – 6 sections from Positive Feedback to Crystal Oscillators. **Systems** – 12 sections from Audio Pre-Amplifiers to 8-Bit ADC plus a gallery showing representative p.c.b. photos.

DIGITAL ELECTRONICS V2.0

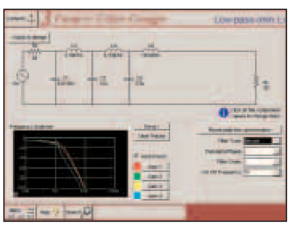
VERSION 2



Virtual laboratory – Traffic Lights

Digital Electronics builds on the knowledge of logic gates covered in *Electronic Circuits & Components* (opposite), and takes users through the subject of digital electronics up to the operation and architecture of microprocessors. The virtual laboratories allow users to operate many circuits on screen.
Covers binary and hexadecimal numbering systems, ASCII, basic logic gates, monostable action and circuits, and bistables – including JK and D-type flip-flops. Multiple gate circuits, equivalent logic functions and specialised logic functions. Introduces sequential logic including clocks and clock circuitry, counters, binary coded decimal and shift registers. A/D and D/A converters, traffic light controllers, memories and microprocessors – architecture, bus systems and their arithmetic logic units. Sections on Boolean Logic and Venn diagrams, displays and chip types have been expanded in Version 2 and new sections include shift registers, digital fault finding, programmable logic controllers, and microcontrollers and microprocessors. The Institutional versions now also include several types of assessment for supervisors, including worksheets, multiple choice tests, fault finding exercises and examination questions.

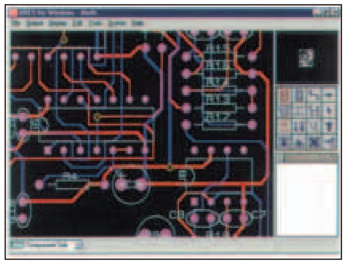
ANALOGUE FILTERS



Filter synthesis

Analogue Filters is a complete course in designing active and passive filters that makes use of highly interactive virtual laboratories and simulations to explain how filters are designed. It is split into five chapters: **Revision** which provides underpinning knowledge required for those who need to design filters. **Filter Basics** which is a course in terminology and filter characterization, important classes of filter, filter order, filter impedance and impedance matching, and effects of different filter types. **Advanced Theory** which covers the use of filter tables, mathematics behind filter design, and an explanation of the design of active filters. **Passive Filter Design** which includes an expert system and filter synthesis tool for the design of low-pass, high-pass, band-pass, and band-stop Bessel, Butterworth and Chebyshev ladder filters. **Active Filter Design** which includes an expert system and filter synthesis tool for the design of low-pass, high-pass, band-pass, and band-stop Bessel, Butterworth and Chebyshev

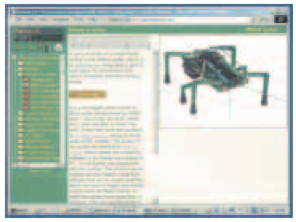
ELECTRONICS CAD PACK



PCB Layout

Electronics CADPACK allows users to design complex circuit schematics, to view circuit animations using a unique SPICE-based simulation tool, and to design printed circuit boards. CADPACK is made up of three separate software modules. (These are restricted versions of the full Labcenter software.) **ISIS Lite** which provides full schematic drawing features including full control of drawing appearance, automatic wire routing, and over 6,000 parts. **PROSPICE Lite** (integrated into ISIS Lite) which uses unique animation to show the operation of any circuit with mouse-operated switches, pots. etc. The animation is compiled using a full mixed mode SPICE simulator. **ARES Lite** PCB layout software allows professional quality PCBs to be designed and includes advanced features such as 16-layer boards, SMT components, and an autorouter operating on user generated Net Lists.

ROBOTICS & MECHATRONICS



Case study of the Milford Instruments Spider

Robotics and Mechatronics is designed to enable hobbyists/students with little previous experience of electronics to design and build electromechanical systems. The CD-ROM deals with all aspects of robotics from the control systems used, the transducers available, motors/actuators and the circuits to drive them. Case study material (including the NASA Mars Rover, the Milford Spider and the Furby) is used to show how practical robotic systems are designed. The result is a highly stimulating resource that will make learning, and building robotics and mechatronic systems easier. The Institutional versions have additional worksheets and multiple choice questions.

- Interactive Virtual Laboratories
- Little previous knowledge required
- Mathematics is kept to a minimum and all calculations are explained
- Clear circuit simulations

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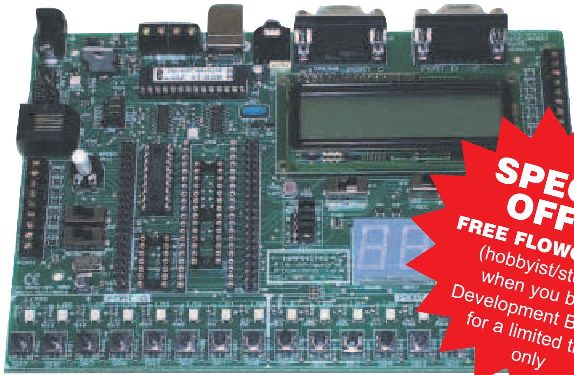

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SOFTWARE

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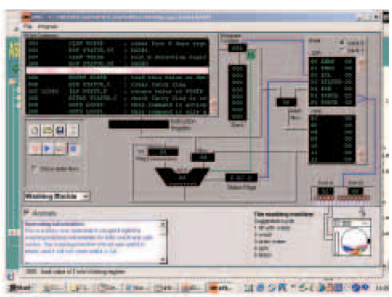
(Formerly PICtutor)

Assembly for PICmicro microcontrollers V3.0 (previously known as PICtutor) by John Becker contains a complete course in programming the PIC16F84 PICmicro microcontroller from Arizona Microchip. It starts with fundamental concepts and extends up to complex programs including watchdog timers, interrupts and sleep modes. The CD makes use of the latest simulation techniques which provide a superb tool for learning: the Virtual PICmicro microcontroller. This is a simulation tool that allows users to write and execute MPASM assembler code for the PIC16F84 microcontroller on-screen. Using this you can actually see what happens inside the PICmicro MCU as each instruction is executed which enhances understanding.
● Comprehensive instruction through 45 tutorial sections ● Includes Vlab, a Virtual PICmicro microcontroller: a fully functioning simulator ● Tests, exercises and projects covering a wide range of PICmicro MCU applications ● Includes MPLAB assembler ● Visual representation of a PICmicro showing architecture and functions ● Expert system for code entry helps first time users ● Shows data flow and fetch execute cycle and has challenges (washing machine, lift, crossroads etc.) ● Imports MPASM files.



'C' FOR PICmicro VERSION 2

The C for PICmicro microcontrollers CD-ROM is designed for students and professionals who need to learn how to program embedded microcontrollers in C. The CD contains a course as well as all the software tools needed to create Hex code for a wide range of PICmicro devices – including a full C compiler for a wide range of PICmicro devices.
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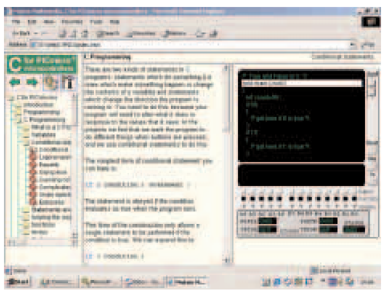

Minimum system requirements for these items: Pentium PC running Windows 98, NT, 2000, ME, XP; CD-ROM drive; 64MB RAM; 10MB hard disk space.

FLOWCODE FOR PICmicro V2

Flowcode is a very high level language programming system for PICmicro microcontrollers based on flowcharts. Flowcode allows you to design and simulate complex robotics and control systems in a matter of minutes.
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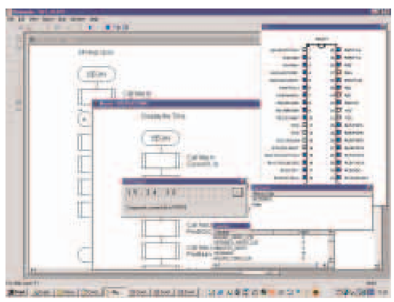
Flowcode produces MPASM code which is compatible with virtually all PICmicro programmers. When used in conjunction with the Version 2 development board this provides a seamless solution that allows you to program chips in minutes.
● Requires no programming experience ● Allows complex PICmicro applications to be designed quickly ● Uses international standard flow chart symbols (ISO5807) ● Full on-screen simulation allows debugging and speeds up the development process ● Facilitates learning via a full suite of demonstration tutorials ● Produces ASM code for a range of 18, 28 and 40-pin devices ● Professional versions include virtual systems (burglar alarm, buggy and maze, plus RS232, IrDa etc.).



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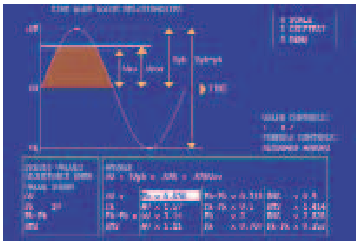

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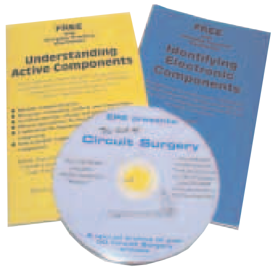

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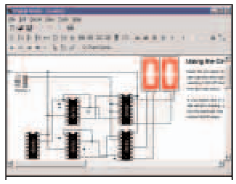
DIGITAL WORKS 3.0



Counter project

Digital Works Version 3.0 is a graphical design tool that enables you to construct digital logic circuits and analyze their behaviour. It is so simple to use that it will take you less than 10 minutes to make your first digital design. It is so powerful that you will never outgrow its capability ● Software for simulating digital logic circuits ●Create your own macros – highly scalable ●Create your own circuits, components, and i.c.s ●Easy-to-use digital interface ●Animation brings circuits to life ●Vast library of logic macros and 74 series i.c.s with data sheets ●Powerful tool for designing and learning.

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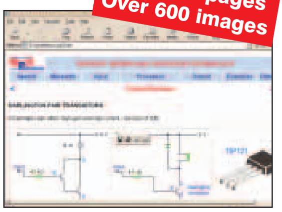

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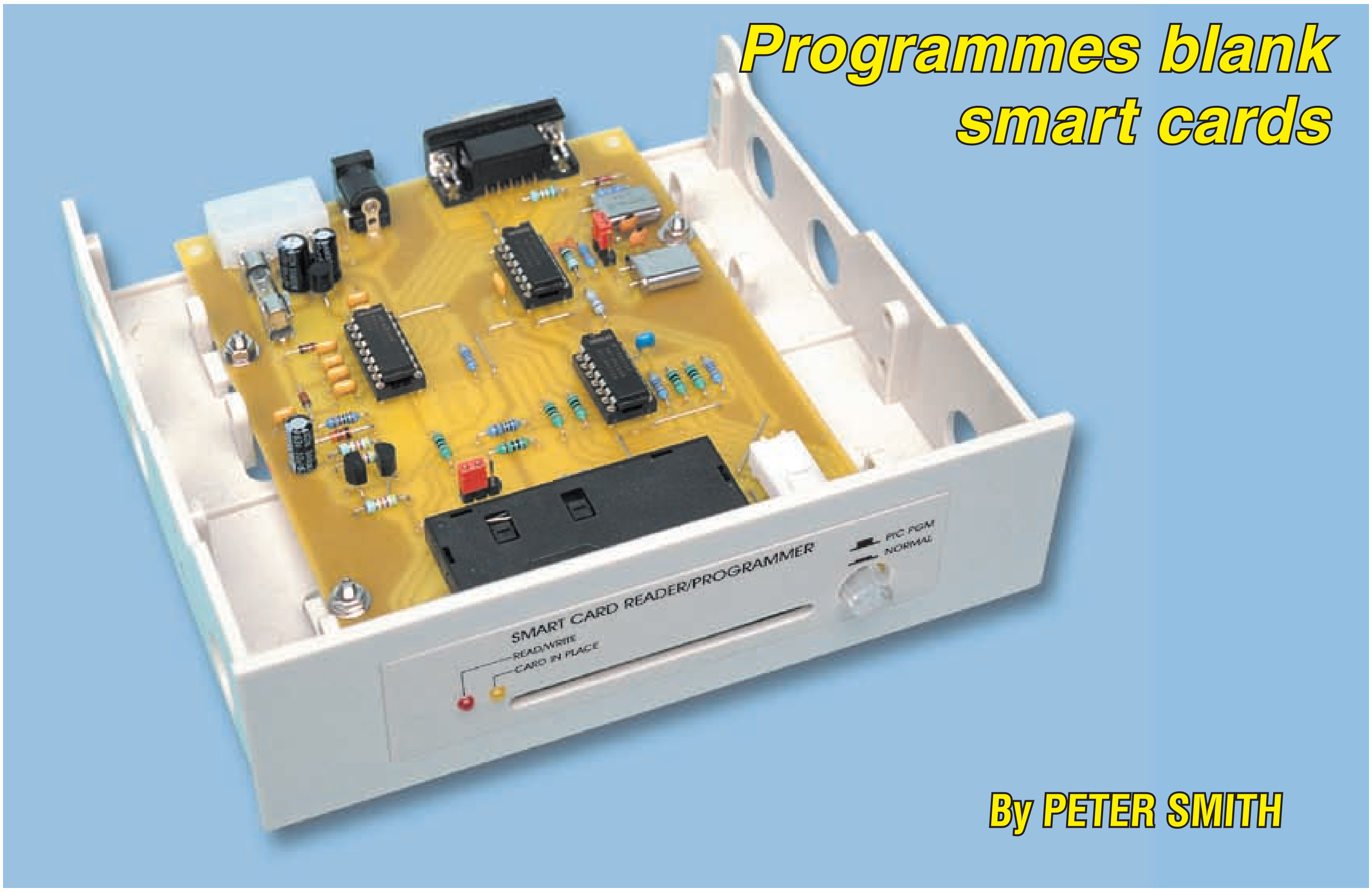


Smart card reader & programmer

This unit allows you to programme both the microcontroller and EEPROM in smart cards. It hooks up to the serial port of your PC and can be operated as a free-standing unit or installed in a PC drive bay.

SMART cards come in dozens of different configurations, with different microcontrollers, memory sizes and even contact positions. However, the cards that we're interested in conform to a recognised set of ISO standards, described in ISO-7816 and entitled "Identification Cards – Integrated Circuit Cards with Contacts".

Parts 1-3 of this document define things like physical dimensions, contact size and position, and interface AC & DC characteristics. They also describe the protocol used to exchange information across the card interface.

Gold wafer cards

Due to their lower cost and available software support, this project targets the "Gold" wafer smart card variety. The Gold card incorporates just two ICs: a PIC16F84(A) and a 24(L)C16 EEPROM. Fig.1 depicts the internal interconnections. As you can see, the EEPROM is not wired to the interface contacts but is controlled exclusively by the PIC.

In a real application, the PIC is programmed with a card operating system. The function of this operating system depends entirely on the card's application but at least one of its tasks is to provide access to EEPROM data via the interface.

With this arrangement, the requirements for EEPROM access are quite straightforward. They entail a relatively simple hardware interface to the

card and some software that can speak the ISO protocol.

Blank cards

But what happens if the PIC's program (Flash) memory is blank? With no card operating system, how do we access the EEPROM? The answer is, of course, that it can't be done with this type of card.

So how *is* the PIC programmed? Well, the connections between the PIC and the card contacts have been designed for dual purposes. As well as supporting "normal" operation, they also allow the PIC to be programmed in-circuit.

This project includes the ability to program the PIC on a blank card. Of course, you can also erase and reprogram the PIC on a used card too, if so desired.

PC connection

Initially, Gold cards and their predecessors were designed for use in set-top boxes and the like. However, it wasn't long before someone interfaced one to a PC serial port and wrote some software to access the internals. This is probably the origin of the so-called "Phoenix" interface.

With a tiny change to the Phoenix interface, it becomes a "Smartmouse" interface, another popular "standard" among the card community. Our design is compatible with both of these interfaces.

How it works

As outlined earlier, the cards that we wish to read and write contain two separate ICs: a PIC microcontroller and an EEPROM (see Fig.1). To access the EEPROM, a Smartmouse or Phoenix-type interface is required. On the other hand, to read or program the PIC's internal memories, a PIC programming interface is required.

Our design solves this conundrum by providing both types of interfaces. A 4-pole 2-position pushbutton switch (S1) is used to select between the two interfaces, or "modes".

Full circuit details for the Smart Card Reader/Programmer are shown in Fig.2. This shows S1 set to the Smartmouse/Phoenix ("normal") position so we'll look at the circuit operation in this mode first.

Smartmouse/Phoenix mode

In this mode, the interface consists of four signal lines: I/O (Input/Output), CLK (Clock), RST (Reset) and Card Detect.

All information exchange between the card and the outside world occurs in half-duplex serial format on the I/O interface line. To help with the explanation, we'll refer to this information as "data". However, actual information exchange may consist of commands (to the card), status (from the card) and EEPROM memory data (to and from the card).

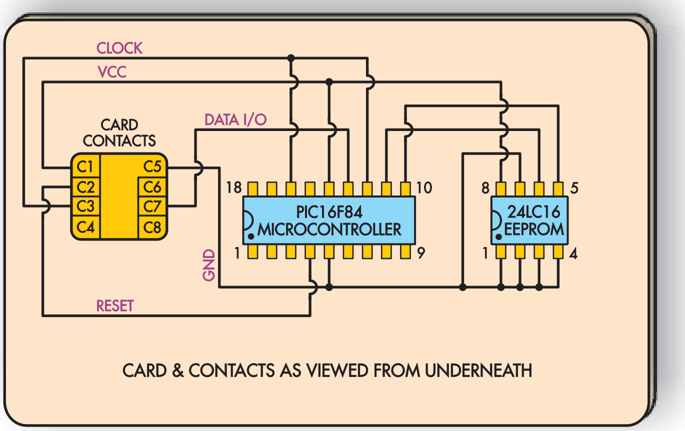
Data from the PC to the smart card is transmitted on the serial port TXD line. It arrives on CON4 (pin 3) and is converted to digital logic levels by the 15kΩ & 100kΩ resistors and clamp diodes D4 & D5. IC2f buffers and inverts the data and it is then applied to the smart card I/O (C7) line via a 4·7kΩ isolation resistor and S1d.

Tracing the I/O line back from the smart card socket, it connects to pin 11 of IC1 via a 470Ω resistor. This path carries data from the smart card back to the PC. It is transmitted on the serial port RXD line (CON4, pin 2) after conversion to RS232 voltage levels by IC1, a MAX232 receiver/driver IC.

Before communication can be established with a card, it must first be initialised to a known state. This is accomplished with the Reset signal, which is controlled by the serial port RTS line (CON4, pin 7). Again, IC1 converts this to a logic-compatible (0-5V) level, after which it is applied to the RST (C2) line of the card via switch S1b.

With jumper JP1 positioned as shown, the RST signal polarity is compatible with the Phoenix-type interface. However, by moving the jumper to position 2-3, the RST signal is inverted by IC3b and the interface becomes Smartmouse compatible.

Fig.1: this diagram shows the internals of a Gold wafer card. If you want to know more about the PIC16F84A and 24LC16 chips, detailed data sheets can be downloaded from www.microchip.com



We fitted our prototype to a standard 3·5-inch to 5·25-inch drive mounting kit which was then slotted into a spare drive bay.

Parts List – Smart Card Reader/Programmer

1 PC board, code 567 141mm × 101mm – available from the *EPE PCB Service*,
1 ICA-700 smart card socket (landing contact style) (CON1)
1 9-way 90° PC-mount female 'D' connector (CON4)
1 4PDT PC-mount pushbutton-slide switch, with green LED indicator (S1 & LED3)
2 M205 fuse clips
1 M205 500mA quick blow fuse
2 3-way 2·54mm SIL header strips
2 14-pin DIL IC sockets
1 16-pin DIL IC socket
2 jumper shunts
1 9-way RS232 cable (D9 male to D9 female, see text)
240mm (approx.) length of 0·71mm tinned copper wire

Semiconductors
1 MAX232 RS232 receiver/driver IC (IC1)
2 74HC04 hex inverters (IC2, IC3)
1 2N3906 PNP transistor (Q1)
1 2N3904 NPN transistor (Q2)
1 78L05 +5V regulator (REG1)
1 1N4004 diode (D1)
4 1N4148 diodes (D2-D5)
1 13V 1W Zener diode (ZD1)
1 3·579545MHz crystal (X1)
1 6MHz crystal (X2)
1 3mm red LED (LED1)
1 3mm yellow LED (LED2)

Capacitors
1 100µF 25V PC electrolytic
2 10µF 16V PC electrolytic
7 1µF 50V monolithic ceramic
1 220nF (0·22µF) 50V monolithic ceramic
1 100nF (0·1µF) 50V monolithic ceramic
2 22pF 50V ceramic disc

Resistors (0.25W, 1%)

1 1MΩ	3 4·7kΩ
1 100kΩ	2 1·5kΩ
3 47kΩ	3 1kΩ
1 15kΩ	6 470Ω
1 10kΩ	1 47Ω

Additional parts for free-standing version
1 2·5mm PC-mount DC power socket (CON2)
9V DC 150mA (min.) plugpack
4 small stick-on rubber feet

Additional parts for PC drive bay-mounted version
1 90° PC-mount disk drive power connector (CON3)
1 3·5-inch to 5·25-inch disk drive mounting adapter & screws
3 M3 x 10mm cheese-head screws
3 M3 nuts
6 M3 flat washers

Where to buy a kit
The design copyright for this project is owned by Jaycar Electronics and complete kits of the freestanding version are available from Jaycar.

If you've worked with PICs before, you'll know that apart from power (VCC) and ground (GND), they also require a clock source to function. This is supplied on the CLK (C3) interface line and is generated by a conventional Pierce oscillator formed by IC2e, a crystal and a few passive components.

To ensure compatibility with a wide range of cards and software, the oscillator frequency can be set to either 3·5795MHz (crystal X1) or 6MHz (crystal X2), depending on the position of JP2. IC2d buffers the oscillator output and series termination is provided with a 47Ω resistor.

Card detection

When a card is inserted, it makes physical contact with a switch at the rear of the socket. One side of the switch is connected to ground, while the other is pulled up to +5V with a 10kΩ resistor. When the contacts close, signalling a fully inserted card, a connection to ground is made through the switch, pulling pin 10 of IC1 low.

After conversion to RS232 levels by IC1, the Card Detect signal appears on serial port lines CD and CTS. Both lines are driven in order to be compatible with various card applications.

Well, that's all there is to the Phoenix/Smartmouse interface. Now let's look at the PIC programming interface, selected when S1 is in the alternative position.

PIC programming mode

Although this mode utilises the same physical connections to the card as those just described, the electrical characteristics of the signals, as well as their connections to the PC serial port, are quite different.

With S1 in the alternative (right-hand) position, the board is transformed into a Ludipipo/JDM-compatible PIC programmer. Compatibility with these types of programmers enables us to take advantage of the many free PIC programming software packages available on the Internet.

In this mode, only three signals are required: DATA, CLK & $\overline{\text{MCLR}}$/VPP.

As before, data is exchanged over a single interface line, now named "DATA". However, in this mode, transmission from the PC occurs on the serial port DTR line (CON4, pin 4). The incoming data is first converted to logic levels by IC1 and then inverted by IC3e. A 4·7kΩ resistor provides the necessary isolation before the signal is piped into the card via S1d on the DATA (C7) line.

Conversely, outgoing data is first inverted by IC3c and is fed via S1c and a 470Ω resistor to IC1 for level conversion and transmission on the CTS serial line.

When in programming mode, PIC micros do not require a conventional clock (oscillator) source. Instead, a signal timed specifically for the programming sequence must be provided on the RB6 pin. Just to confuse matters, this signal is still referred to as "CLOCK".

The CLOCK signal originates from the serial port RTS line. Once again, IC1 does the level conversion after which the signal is inverted by IC3b and fed to the card via S1a.

VPP generation

Many early PIC micros, including the PIC16F84(A), must be supplied with a high voltage (12·5V to 13·5V) during programming of the internal Flash and EEPROM memories. Our design uses a unique method of generating this programming voltage (V_{PP}).

The voltage boosting circuitry is based around IC1, a MAX232 RS232 line driver and receiver IC. Of interest is the method that this chip uses

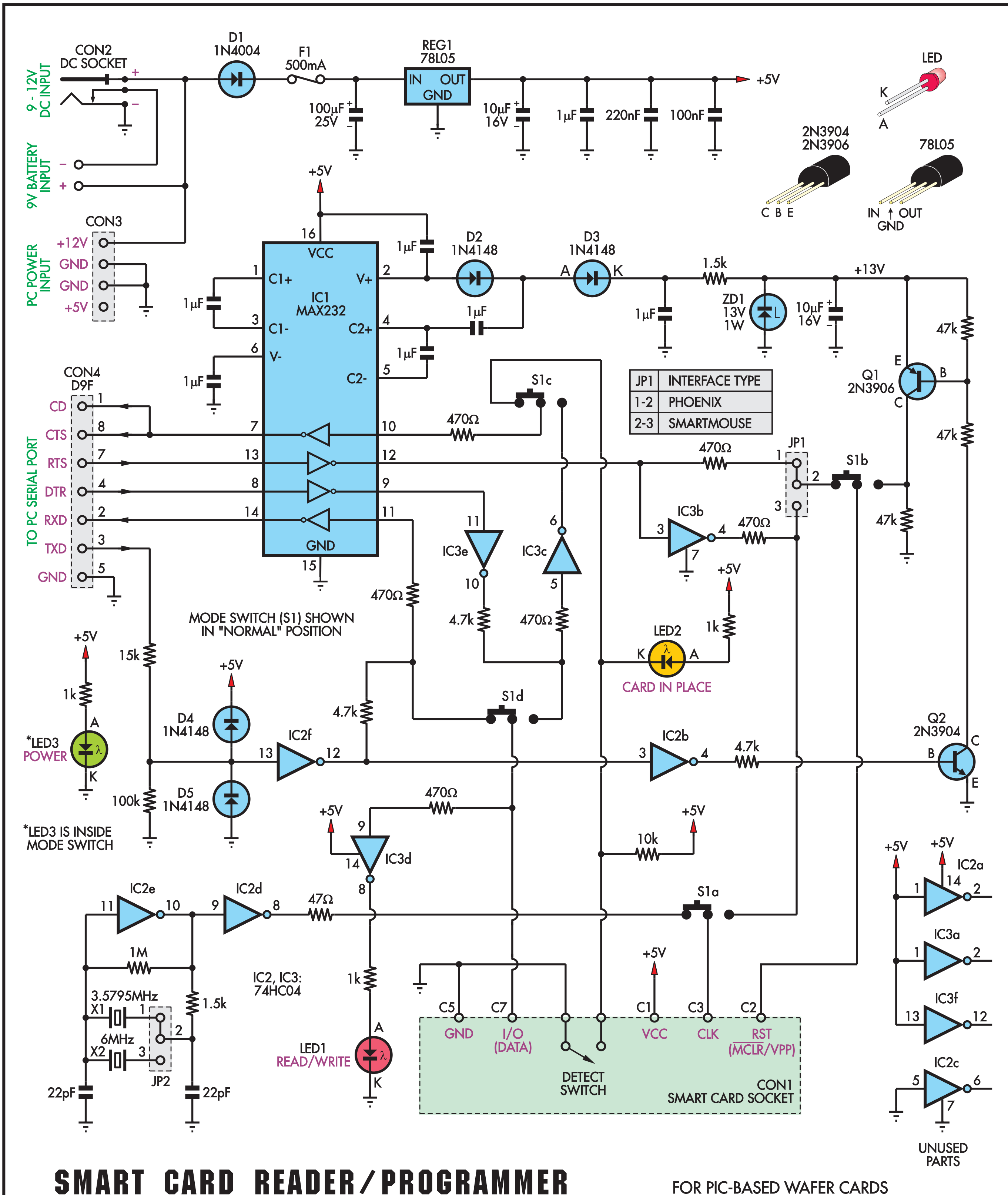


Fig.2: the complete circuit diagram of the Smart Card Reader/Programmer. Slide switch (S1) is central to its operation, routing signals between the PC's serial port and the card interface according to the selected mode.

to generate the ±10V needed for the RS232 interface.

Basically, internal switches combined with four external 1µF capacitors form two charge-pump voltage circuits, one doubling the supply (V_{CC}) voltage to +10V (nominal) and the other inverting the result to obtain −10V.

By adding diodes D2 & D3 and a 1µF capacitor to pin 4, we've extended the capability of the chip to create a voltage quadrupling circuit.

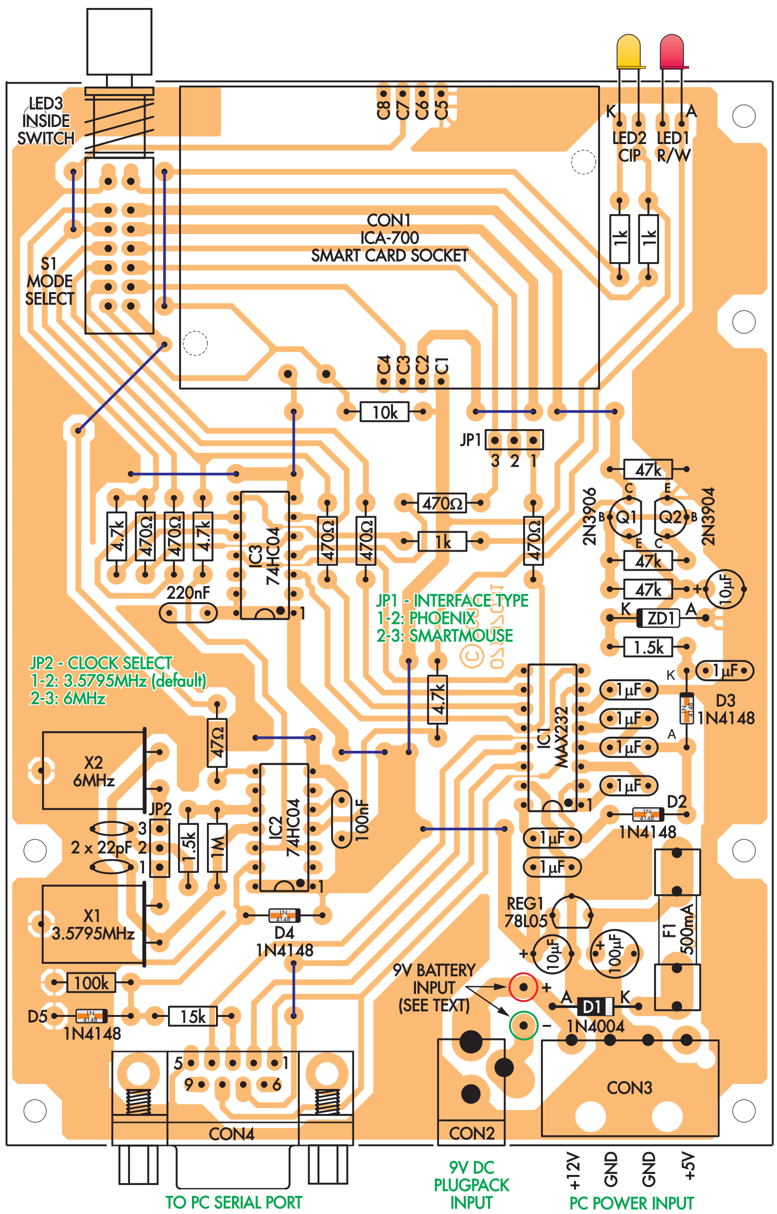


Fig.3: refer to this full-size overlay diagram when assembling the board. Be careful not to install any of the diodes, electrolytic capacitors or ICs in reverse. They must be oriented exactly as shown here.

Table 2: Capacitor Codes

Value	μF Code	EIA Code	IEC Code
220nF	0·22μF	220n	224
100nF	0·1μF	100n	104
22pF	22pF	22p	22

With the losses across the diodes, as well as the loading imposed by the RS232 drivers and the V_{PP} regulation circuitry, the result at the cathode (K) of D3 is less than four times the V_{CC} supply (around 15·6V). However, this is more than adequate for our purpose.

Zener diode ZD1 and its 1·5kΩ series resistor form a shunt regulator, ensuring a reliable 13V V_{PP} supply. We've biased the Zener with as little current as possible to minimise loading on the MAX232. If the add-on circuitry were to draw more than a few milliamps, it would load down the converter circuitry, lowering the RS232 voltage levels below the specified minimums.

During PIC programming and verification, the 13V (nominal) V_{PP} voltage is switched through to the $\overline{MCLR}/V_{PP}$ (C2) line of the card socket with the aid of transistors Q1 & Q2 and their associated bias resistors.

The V_{PP} enable signal originates from the serial port TXD line. It is first converted to logic (0-5V) levels by the 15kΩ & 100kΩ resistors and clamp diodes D4 & D5. Next, it is inverted by IC2f and inverted again by IC2b before driving the base of switching transistor Q2.

When Q2 switches on, it pulls Q1's base towards ground, turning it on and thus switching V_{PP} through to the card socket (via S1b). A 47kΩ resistor

Table 1: Resistor Colour Codes

❑	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	1	1MΩ	brown black green brown	brown black black yellow brown
❑	1	100kΩ	brown black yellow brown	brown black black orange brown
❑	3	47kΩ	yellow violet orange brown	yellow violet black red brown
❑	1	15kΩ	brown green orange brown	brown green black red brown
❑	1	10kΩ	brown black orange brown	brown black black red brown
❑	3	4·7kΩ	yellow violet red brown	yellow violet black brown brown
❑	2	1·5kΩ	brown green red brown	brown green black brown brown
❑	3	1kΩ	brown black red brown	brown black black brown brown
❑	6	470Ω	yellow violet brown brown	yellow violet black black brown
❑	1	47Ω	yellow violet black brown	yellow violet black gold brown

from $\overline{\text{MCLR}}/V_{PP}$ to ground ensures that the PIC is held in the reset state when the V_{PP} supply is switched off.

Note that the (newer) PIC16F87X and PIC16F62X series micros used in the Silver and Emerald cards do not require high voltage for programming. However, Microchip has retained support for this programming method to ensure backward compatibility. Therefore, this project should be able to successfully program the PICs in all of these cards, given the appropriate software.

Read/Write LED

LED1 indicates activity on the I/O signal line. Due to the inversion of data between Normal and PIC Programming modes, this LED will either pulse dimly or appear to be mostly on, with a perceptible flicker during data exchange.

Power supply

When used as a free-standing unit, a 2·5mm DC socket (CON2) accepts power in the 9-12V DC range. This is suitable for connection to a low-cost, 9V DC unregulated plugpack (positive to centre pin).

For use with a laptop PC, the unit can also be powered from a 9V battery. The PC board will accept a pair of 1mm pins for connection to the battery leads (see Fig.3). Note that you'll need to fit an in-line switch, as the current drain is quite high (about 35mA with the card inserted) and this would quickly exhaust a PP3 battery.

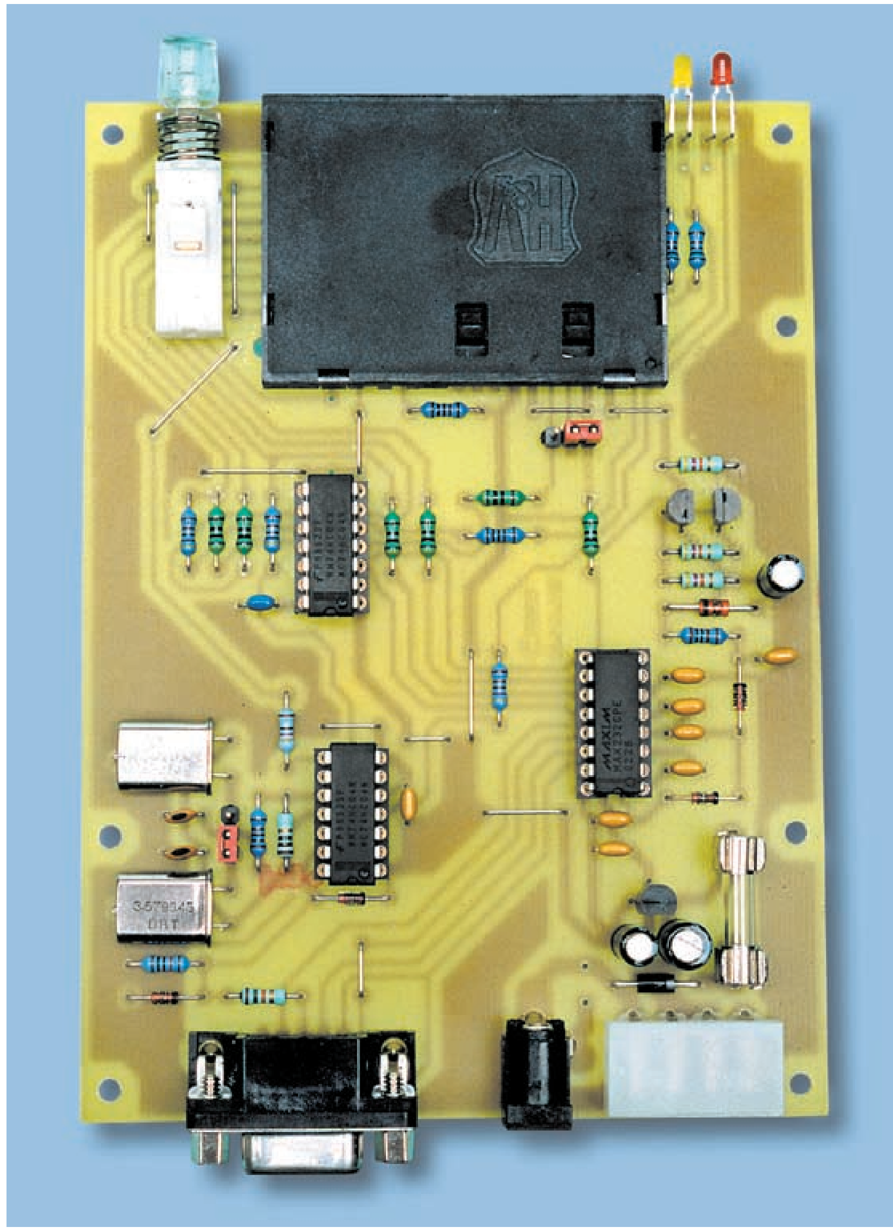
When installed in a PC drive bay, 12V DC is sourced from the PC power supply via CON3, which is a disk drive power socket.

Regardless of the power source, diode D1 provides reverse polarity protection. A 500mA series fuse is included for safety reasons and will open only in the case of serious failure.

Following the fuse, a 100µF capacitor smooths the input before it is applied to a conventional 3-terminal regulator (REG1). All circuit elements are powered from the regulator's +5V output. In addition, the regulator's inbuilt current limiting feature, which comes into play at about 140mA, protects the board if a faulty smart card is inserted.

Construction

All components mount on a single PC board, measuring 141mm × 101mm



The Smart Card Reader/Programmer board connects to a spare serial port on your PC via a standard RS232 cable (D9 male to D9 female). Note that this prototype includes both power sockets (only one normally required).

and coded 567 (available from the *EPE PCB Service*). Referring to the overlay diagram in Fig.3, begin by installing all 12 wire links using 0·7mm tinned copper wire or similar.

Follow up with all the low-profile components. Resistors first, then diodes (D1-D5, ZD1), transistors (Q1, Q2), regulator (REG1) and capacitors. Note that the diodes must be installed with the cathode (banded) ends oriented as shown.

Orientation of the 10µF and 100µF electrolytic capacitors is important too. Their positive sides must be aligned as indicated by the "+" symbol on the overlay.

The two crystals (X1, X2) can go in next. They mount in a horizontal fashion, so bend the leads at 90° (about 2mm from the body) before installation. After installation, connect the crystal cans to ground by soldering a short length of tinned copper wire to the top of each can and to the pad directly underneath (see photos).

Fit the connectors (CON1-CON4), the two 3-way jumper headers (JP1 & JP2) and mode switch (S1) next. Take care to ensure that these components are seated all the way down on the PC board surface before soldering them.

Note that it is not necessary to install both CON2 and CON3. If you'll

be mounting the finished project in a PC, install CON3. If you'll be using it stand-alone, install CON2 instead.

Install the two fuse clips next. Note that the small retaining lug on each clip must be positioned to the outer (fuse end) side, otherwise fuse installation will be impossible.

The three ICs (IC1-IC3) and the two LEDs (LED1 & LED2) should be installed last of all. The orientation of these devices is very important. Align the "notched" end of the ICs (the pin 1 end) as shown in Fig.3.

If you're building a freestanding unit, you can also install the LEDs now. The flat (cathode) sides should face the smart card socket. If you intend fitting the board in a PC or other enclosure, it's best to leave the LEDs out until you've prepared the front panel and can gauge the required lead length.

Testing

It's a good idea to apply power and perform a few quick checks before inserting a smart card, so let's do that next.

Plug in your chosen power source and switch on. No smoke? Good! Set your multimeter to read volts and measure between pins 7 & 14 of both IC2 and IC3. Your meter should read about 5·0V in both cases.

For the remaining tests, connect the negative probe of your meter to any handy ground point (say, the anode of D5 or one of the crystal cases). Now measure pin 2 of IC1 with the positive probe. The reading should be about 8·7V or more. Now move to pin 6 of IC1 – expect at least – 7·8V here.

Next, measure the cathode (banded) end of D3. If all is well, there should be 15·6V or more at this point. Finally, measure at the cathode of ZD1. Assuming that the shunt regulator is doing its job, the VPP voltage will be pretty close to 13·0V.

Housing

For a freestanding unit, all you need do is fit four small self-adhesive rubber feet to the underside of the board.

Alternatively, the board can be installed in a spare drive bay in your PC. The preferred method is to first mount the board in a 3·5-inch to 5·25-inch plastic disk drive adapter and then fit this into a spare 5·25-inch drive bay, as shown in the photos.

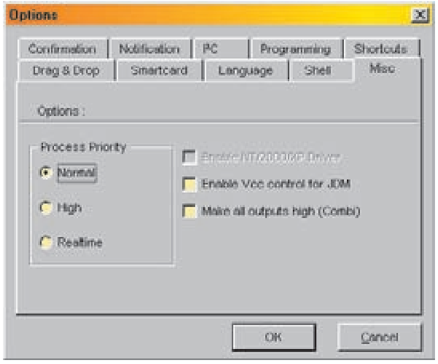


Fig.4: to enable the serial/parallel port driver, check the "Enable NT/2000/XP Driver" box (see text). Note that this option is disabled on Windows 9x/Me, as the driver is not needed for these versions of Windows.

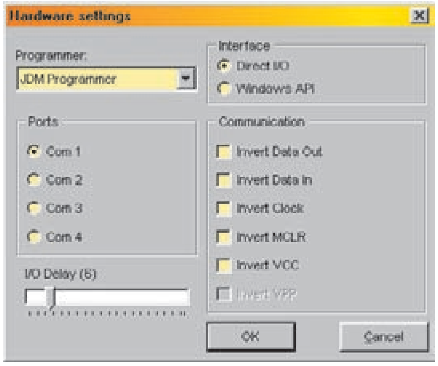


Fig.5: this is what your hardware settings should look like. You may need to increase the I/O Delay slider by a few points if you get the occasional verify error but start off with the default value of (6).

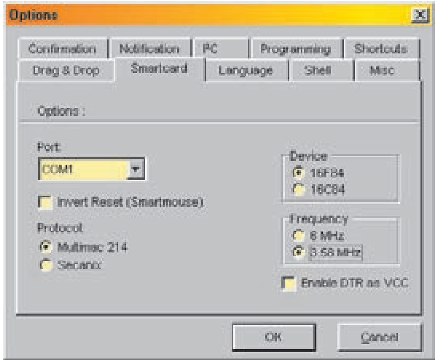


Fig.6: the default values for IC-Prog's smart card settings. Not all cards support the 6MHz clock rate, so select the "3.58MHz" setting for maximum reliability. Jumper JP2 on the PC board should be set to agree with the frequency selected here.

If your power supply lacks a spare drive power connector, you can purchase a "Y" cable splitter from most computer outlets.

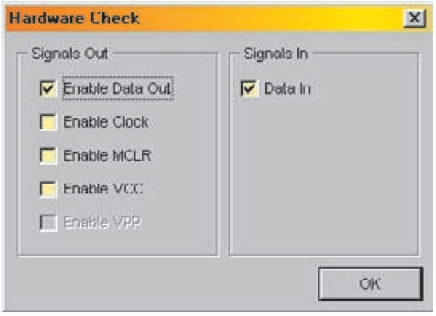


Fig.7: if you can't get PIC programming mode to work, IC-Prog's "Hardware Check" feature might help. Clicking in these boxes toggles the indicated signal lines, providing a very useful fault-finding aid.

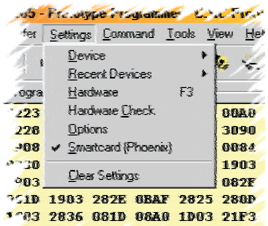


Fig.8: make sure that there is a tick against the "Smartcard (Phoenix)" option on the Settings menu.

The serial port cable can be routed out through any convenient exit point at the rear of the case for connection to a free serial port.

We cut down an old 5·25-inch drive blanking plate to fill the hole in the front of the adapter. To save time and effort, you could also use a piece of much thinner plastic or even cardboard for the job. You can photocopy the front panel label in Fig.12 and use it as a template for the hole and slot positions.

Installing the software

Being compatible with several popular serial port-connected programmers, your new board will work with much of the freely available card software on the Internet. We've selected "IC-Prog" for our demo, primarily because it runs on many versions of Windows (Win9x/Me and Windows NT/2000/XP) and also because it can program both the PIC and EEPROM in Gold cards.

You can obtain the latest version of IC-Prog from **www.ic-prog.com**. In all, you'll need to download three files: the application (icprog105a.zip), the driver for Windows NT/2000/XP (icprog_driver.zip) and the help file (icprog.chm). Note that the filenames will change over time as IC-Prog is improved and updated.

Unlike most Windows applications, IC-Prog is not self-installing,

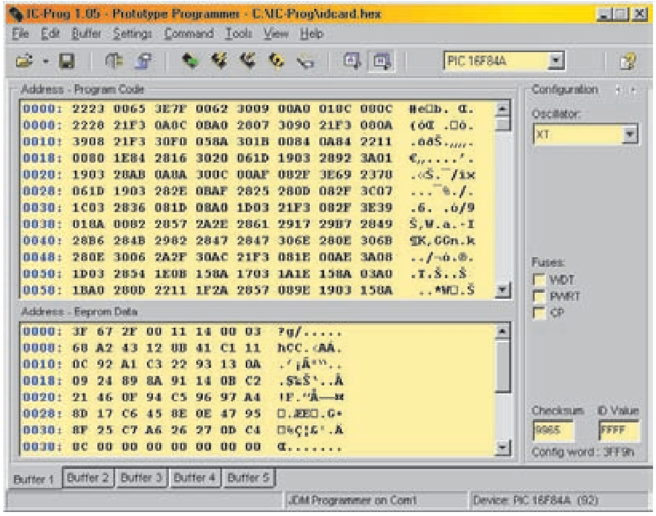


Fig.9: this shot was taken just before we hit the "Write All" button. We've selected the correct type of PIC, loaded the .HEX file and double-checked the configuration bits. Note that if the CP (code protect) bit is enabled, it will be impossible to read or verify the PIC

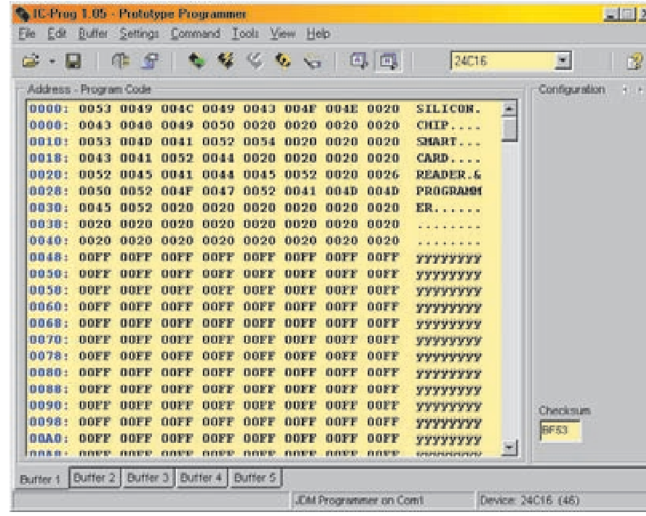


Fig.10: once the PIC has been successfully programmed, select the 24C16 device from the drop-down menu. The card's EEPROM should then be fully accessible.

Fig.11: this message will appear if IC-Prog can't talk to the PIC. Assuming that the PIC has been successfully programmed (with the correct loader), it probably means that you haven't switched modes. It might also mean that the crystal oscillator either isn't oscillating or is set to 6MHz when it should be 3·58MHz. Also, make sure that the positions of JP1 and JP2 match the complementary settings on the "Smartcard" tab.

so you'll need to manually create a folder to contain the files. We named ours "C:\IC-Prog". It's then just a matter of unzipping the first two files into the new directory, and creating a shortcut on your desktop (or Start menu) to "icprog.exe". The help file (icprog.chm) should also be saved in this new folder.

Installing the port driver

For Windows NT/2000/XP users, the serial/parallel port driver should be installed as the next step.

Launch IC-Prog (ignore any error messages) and from the main menu select *Settings* -> *Options*. Click on the *Misc* tab and from the list of displayed options, click on the "Enable NT/2000/XP Driver" check box (do not change any other settings on this tab!). Follow the prompts to restart your machine so that the driver can be installed and started.

Note: if the port driver is not properly installed, you will get a "Privileged Instruction" error whenever IC-Prog attempts to access the serial port.

Before use, IC-Prog must be set up to suit the programming hardware.

Setting up IC-Prog

From the main menu, select *Settings* -> *Hardware* to bring up the "Hardware Settings" dialog (see Fig.5). Choose "JDM Programmer" as the programmer type and "Direct I/O" as the interface method. You should also select the COM port that you'll be using with the programmer. No other settings in this dialog should be changed (do not check any of the "invert signal" options!) at this stage.

Next, select *Settings* -> *Options* and click on the *Smartcard* tab. From the drop-down list, select the appropriate COM port. If your card is set for Smartmouse compatibility (JP1 pins 2-3 shorted), you should select the "Invert Reset" option. From the remaining settings, choose "Multimac 2·14", "16F84" and "3·58MHz". Now click on the OK button to save the settings and close the dialog.

Finally, select *Settings* -> *Smartcard (Phoenix)*. A tick should now appear against this option in the Settings menu, indicating that smart card programming mode is enabled (see Fig.8).

Programming the PIC

If you're an old hand at card programming, then you'll probably have all the necessary files ready to go. In this case, IC-Prog includes a "Card Wizard" feature to enable you to program your card in short order. However, much more flexibility is afforded if we bypass the Wizard and perform each task individually.

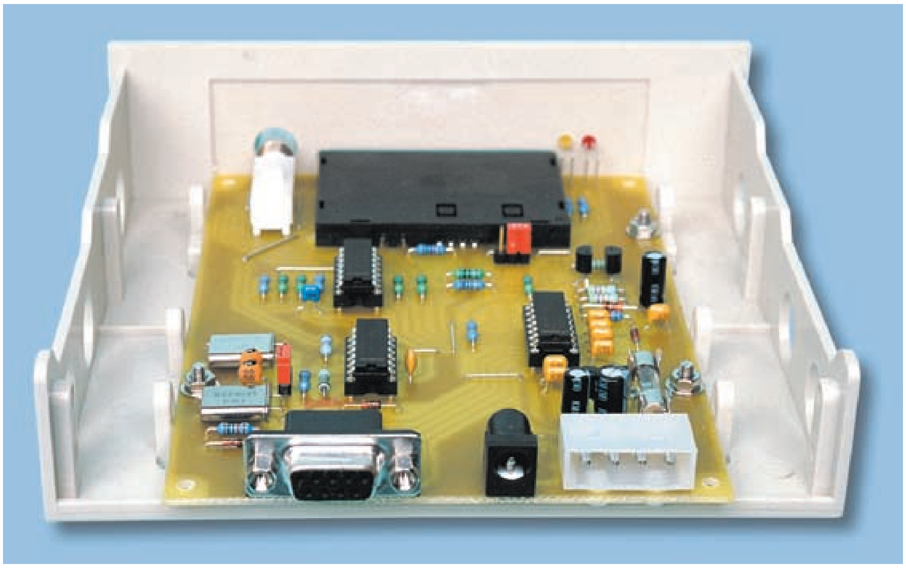
For blank cards, the first task is to program an operating system (OS) into the PIC micro. This operating system will then enable us to access the on-card EEPROM. This is often referred to as "through-PIC programming".

The operating system can be any generic one that provides full EEPROM access over a Phoenix/Smartmouse-type interface. Various versions are freely available on the Internet and are often called "loaders", after the fact that they're sole purpose is to "load" the EEPROM.

Not all loaders are created equal. Look for one in Intel HEX file format (.hex or .h8) that is Multimac 2.14 (or later) compatible and targeted for the 16F84. We downloaded our card OS from **www.maxking.com/ZIPS/rb-7hex.zip**

To program the loader into the PIC, select the appropriate PIC device from the drop-down list on the main menu. For Gold cards, choose the PIC16F84A. Next, select *File* -> *Open File* and navigate to wherever you unzipped the loader. Double-click on the file to open it, and the contents will appear in the main IC-Prog window.

Before you "burn" your card, double-check that the micro configuration bits (displayed on the right side of the



This view shows how the PC board is fitted to a standard 3·5-inch to 5·25-inch drive mounting kit. We cut down an old 5·25-inch drive blanking plate to fill the hole in the front of the adapter.

main window) are set correctly. The oscillator type should always be set to "XT" for smart cards. For the 16F84(A), the WDT & PWRT bits should be disabled (not checked) unless the loader documentation indicates otherwise. It's also unlikely that you'll want the CP (Code Protect) bit enabled.

Make sure that the programmer is in PIC programming mode (switch out) and that the power is on. Now insert a blank card (contacts facing down and towards the slot) into the programmer. You should feel it slip all the way home with a slight click and the "Card In Place" LED should light. OK – hold your breath and click on the "Program All" button on the toolbar.

If all goes well, the PIC will be programmed and then verified successfully. If the verify fails, try erasing the PIC (click on the "Erase All" button) and re-run the programming.

Programming the EEPROM

Once PIC programming completes successfully, switch the programmer to Phoenix/Smartmouse (normal) mode (switch in). Now select the appropriate EEPROM device from the drop-down list on the main menu. For Gold cards, this is the 24C16 device.

At this point, you can read and/or write to the 24C16 EEPROM inside the card. You can read the contents and edit them directly in the IC-Prog window, or load and write whatever data file you desire to the EEPROM.

Note: to be able to access the on-card EEPROM, you must have enabled IC-Prog's smart card programming mode, as described under "Setting up IC-Prog" above.

Preventing card damage

The smart card socket specified for this project uses "landing contact" technology. This means that the socket contacts do not touch the contacts on the card until it is almost fully inserted.

The advantage of this method is that there is little possibility of power and ground being momentarily connected to the wrong set of pins, as might occur with wiping contacts. It also results in less card wear.

However, to further minimise the possibility of damage to the electronic circuitry, it's important to follow a few simple rules during use. First, before inserting or removing a card, the programming software should be running (but not reading or programming, of course!). This ensures that the serial port is in a known state and that all the control lines properly initialised.

Second, do not switch modes when reading or programming is under way. If you find you've inadvertently left the mode switch in the wrong position before initiating a read or write, then simply let it complete (no damage will occur) before switching over.

Programming other cards

Our descriptions have dealt exclusively with the Gold-type wafer cards. However, this project is capable of reading and programming most PIC-based cards. It has been successfully tested with the Emerald (PIC16F628 & 24LC64) and Silver (PIC16F877 & 24LC64) cards.

Both of these cards can be programmed with IC-Prog (don't use the Card Wizard function). However, separate loader programs are required for each of the cards, as the PIC16F84 version (used with the Gold card) will *not* work with these newer devices. We're yet to find a source for PIC-16F628 & PIC16F877 loaders. Note: this project will not work with any Atmel-based cards.

Now what?

Now that you can read and write a smart card, what do you do with it?

Fig.12: photocopy this diagram and use it as a drilling & cutting template for the drive bay blanking plate.

We found several simple applications, including door access control, identity card, time clocking and PC security at **www.maxking.co.uk**. You can download these free of charge but note that they are only demos and some can be a little "buggy"!

If you can program in Visual Basic or C/C++, then you'll find a well-documented API DLL for Windows at **www.gis.co.uk**. This library gives full access to the Smartmouse interface, considerably easing the programming task.

Note that the site lists files for a number of different card readers. This project is compatible with the SM1-RS232 model.

The files of interest are named "sm-12dll.exe" and "usref3_0.pdf".

More information

As usual, information on the ISO-7816 smart card standard abounds on the *Internet*. Point your browser to **www.google.com** and search for "ISO7816". Microsoft and others are involved in defining standards for smart cards connected to PCs. Check out **http://msdn.microsoft.com/library/en-us/dnscard/html/msdn_smart_card.asp** and **www.pcscworkgroup.com** for details.

We've yet to find applications of a non-commercial nature that have exploited the full potential of these useful little devices.

Sadly, much of the information on the Internet is related to card "hacking". Perhaps you could be one of the enthusiasts to put them to real use! ***EPE***

Net Work

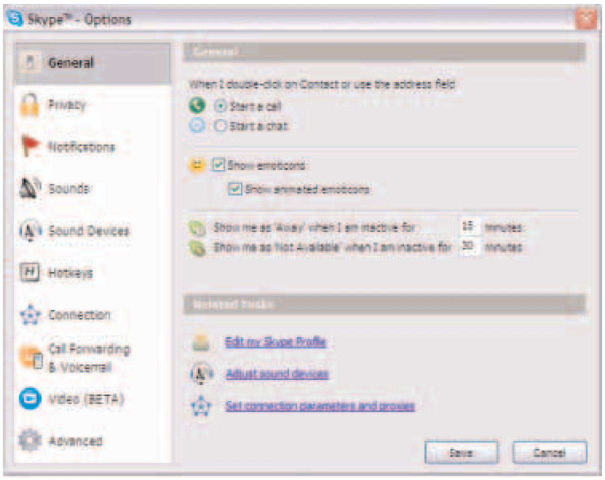
Alan Winstanley

Let's Start with Skype!

Last month I introduced some of the most popular Internet communications packages that allow voice and video communications with other users anywhere in the world. Armed with a broadband connection and possibly a webcam, it is now extremely simple to call friends or family using one of the most popular services available, **Skype (www.skype.com)**.

The core Skype service is free: Skype makes no subscription charge, so you can call your contacts on Skype for free over your broadband connection. You can also "dial out" to non-Skype users in order to place voice calls to any telephone in the world. The "Skype Out" service involves buying Skype credits, which are used to fund the cost of calls to ordinary landlines.

Skype is probably the easiest package that will get you chatting over the Internet and is the one I recommend. This month, for the benefit of computer beginners, I'll be looking at making the first steps with Skype, highlighting some important considerations along the way. The first port of call is Skype's website, in order to download Skype 2.0 for Windows (also available for Mac OS X, Mobile and Linux users). This is a 9.5MB download. Simply run the software (double-click the file) to commence setup and installation.



The Options panel in the Skype software is simple to use and unintimidating, which will appeal to computer beginners

The next step is to choose your own Skype Name and password, which identifies you to other Skype users. Just like many other popular services such as eBay or Hotmail, it is increasingly hard to find something unique: it is worth clicking Skype's Search icon to find any similar names, and try to choose something that is sufficiently different from existing names. You don't have to reveal any personal information at all in your Personal Profile, and it is wise to generalise your location details (such as "UK") without being any more specific. Assuming you are online, you can then log in with your new Skype name and password.

At this stage you will not have any Skype contacts to call – and before you start adding contacts, I recommend using Tools/ Options in the software to check out the various configuration menus. They are very straightforward and there is nothing to cause concern to the novice Skype user.

Check Your Privacy

I strongly recommend checking the Privacy defaults as follows:

Allow Calls From
- Only people from my Contacts

Allow Chats From
- Only people from my Contacts

This prevents unwanted intrusions from Skype users that are not on your Contacts list. In the Advanced options, untick the option "Automatically answer incoming calls", so that you can decide whether or not to accept them. For reference, bear in mind that the "Skype Me" mode is an open invitation for anyone to contact you, and it overrides your Privacy settings when selected. Only the more adventurous should select it.

Now plug a microphone/headset into the sound card of your PC, or use separate speakers and microphone (or, a webcam with built in microphone – see next month). Perfectly good results can be obtained with a modestly-priced audio headset, though one having a noise-cancelling microphone boom may help. On the author's system, this plugs into colour-keyed sockets on the desktop loudspeakers at times when privacy is desirable.

You can make a test recording to Skype as follows: in Options/ Sound Devices, click the link "Make Test Call to Skype answering machine". A pre-recorded welcome message plays and explains what to do next. You can record a ten-second message, and Skype will then play it back. If you can hear your recording properly then your sound system is now set up. If you have problems with volume, try to find the audio settings in the Windows Control Panel under Sounds and Audio Devices, and see if you can adjust the sound levels to suit.

Also under Sound Device options, check the box "Ring PC speaker" so that you can hear someone calling you, even if the headset is plugged in and you're away from your workstation. If you hear no sound at all, check the microphone – is it plugged into the correct socket? (On a PC sound card, it is a pink-colour 3·5mm jack). And is the loudspeaker plugged into the right socket?

The remaining options are largely self-explanatory, thanks to the clean and simple design of the Skype software. Take a look around them. Also go to File/ Edit My Profile… to check settings or set up your own avatar image (a small thumbnail image that your contacts will see in their contact list). An adjacent text box lets you type a pithy phrase that will also be displayed.

Making Contacts

You can now choose to add Contacts to your list. The Search icon provides a range of criteria including location and email address. Double-clicking a contact in your list will start either a voice call or chat session (choose which, in the General tab in options). Tidy up your Contacts names, if you like, by right-clicking the Skype name and renaming it to something you feel is more recognisable.

Starting a call couldn't be easier than choosing a contact, pressing a green Call button to start, and the red button to hang up. Skype chat is useful for quick messaging with friends. You now know enough to get started with Skype.

Next month, I will provide some pointers on choosing a suitable webcam and I'll explain the basics of video communications with Skype. You can email the writer at **alan@epemag.demon.co.uk**

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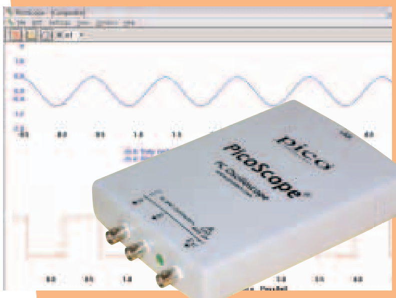

If you have a novel circuit idea which would be of use to other readers then a Pico Technology PC-based oscilloscope could be yours. Every 12 months, Pico Technology will be awarding a PicoScope 3205 digital storage oscilloscope for the best IU submission. In addition a DrDAQ Data Logger/Scope worth £59 will be presented to the runner up.

Our regular round-up of readers' own circuits. We pay between £10 and £50 for all material published, depending on length and technical merit. We're looking for novel applications and circuit designs, not simply mechanical, electrical or software ideas. Ideas *must be the reader's own work* and **must not have been published or submitted for publication elsewhere.** The circuits shown have NOT been proven by us. *Ingenuity Unlimited* is open to ALL abilities, but items for consideration in this column should be typed or word-processed, with a brief circuit description (between 100 and 500 words maximum) and include a full circuit diagram showing all component values. **Please draw all circuit schematics as clearly as possible.** Send your circuit ideas to: *Ingenuity Unlimited,* Wimborne Publishing Ltd., 408 Wimborne Road East, Ferndown, Dorset BH22 9ND. (We **do not** accept submissions for IU via email). Your ideas could earn you some cash **and a prize!**

Automatic Doorball – *Closely Turned On*

THE circuit diagram shown in Fig.1 detects the presence of a visitor at the door and rings the doorbell automatically. The doorbell will only ring once until the visitor moves away from the sensor for over one minute. The doorbell will not ring when the user opens the front door.

The input sensor is a normal PIR Motion Detector of the "Pet Motion" type, X1, set to slow mode to eliminate the possibility of false triggering. Its output feeds into one input of a triple AND gate, IC1a, biased normally high by resistor R1. The gate's output is high when activated.

A magnetically operated switch, S1, on the door-frame disables the circuit when the door is open. Its output, biased normally-high by resistor R2, feeds into inverter IC2a. When the door is closed, the switch output is low, and the inverter's output high, enabling the second input of AND gate IC1a.

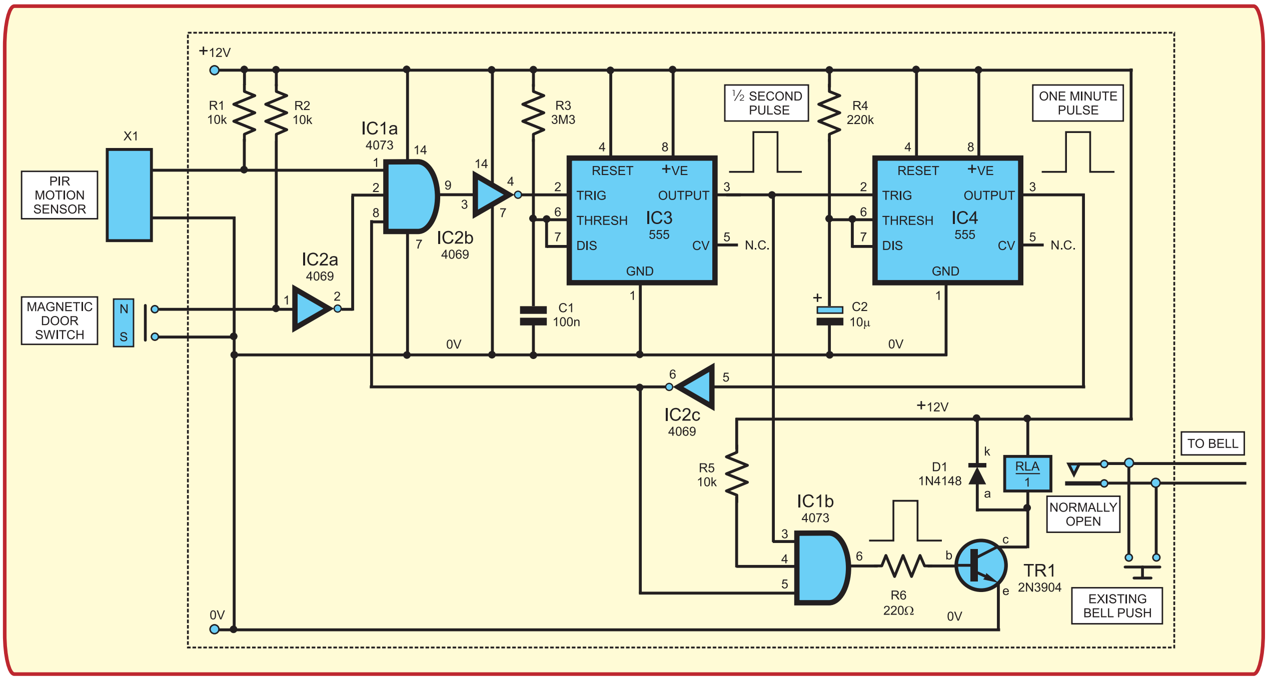

Fig.1. Complete circuit diagram for the Automatic Doorbell

Under normal standby conditions, the third input to IC1a is held high by the output of IC2c, and IC1a's output is also high. Under these conditions, when the PIR sensor is activated, so too is timer IC3, generating a positive-going output pulse at pin 3 lasting about 0·5 seconds, as determined by the timing value set by resistor R3 and capacitor C1.

This pulse triggers AND gate IC1b, whose other inputs are held high at this time by the high bias of resistor R5 and the high output of IC2c. The high output of IC1b turns on transistor TR1 via resistor R6, activating relay RLA.

The normally-open contacts of the relay are now closed, closing the contact leads of the existing manual bell switch, so turning on the bell for half a second. (The normal bell-push can be omitted if preferred.)

When the pulse from IC3 ends, it triggers timer IC4, producing a positive-going pulse lasting for about one minute as set by resistor R4 and capacitor C2. This disables one input of each of AND gates IC1a and IC1b, and so further activation of the bell cannot occur until that one minute pulse has ceased.

The same 12V supply that supplies motion detector X1 can power the circuit.

Chris Hegter, South Africa.

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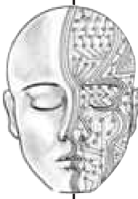

PIC N' MIX

MIKE HIBBETT

Our periodic column for your PIC programming enlightenment

PIC Circuit & Software Reliability

SINCE microcontrollers first became available to hobbyists in the 1970s, their use has grown steadily and they are now as ubiquitous as the transistor. Fully featured devices such as those found in the Microchip PIC product range have become a natural choice in our hobby designs.

As the complexity of designs increase, a problem arises: software reliability. Programs running on silicon deep inside IC packages cannot be seen or viewed on an oscilloscope. When we try to judge the correctness of a design we frequently rely on blind faith; once the assembler reports "0 Errors found" and the code runs, we pat ourselves on the back and consider the job well done.

So What's Wrong?

So what's wrong with this approach to designing software?

First, we must remember that there are likely to be many pathways in our software, different sequences of code that the CPU can execute. As the code size grows beyond a few hundred bytes the permutations explode. We might think that the CPU is running through a large proportion of the code ("After all, it is running at 10 million instructions per second!") but in fact it is not unusual for the "code coverage" – the proportion of code actually executed – to be as low as 20% during normal operation. Unusual key combinations, data values, error handling code and such like can get overlooked during software testing and may simply not work at all, lying hidden in the code until the worst possible moment.

As though that is not bad enough, there are other, subtler, problems that we must contend with. Electrical noise coming from internal inductive devices such as relays, crosstalk from switching signals and external influences such as ESD can cause a microcontroller to behave in the most unusual and erratic manner.

To understand the causes of these problems we need to consider how the microcontroller works. The program counter, status register, stack and all peripheral control registers are implemented in RAM, like normal variables. Each RAM "bit" typically consists of four transistors wired in a flip-flop configuration, and while power is supplied to the RAM it is in a stable state. The state (i.e. the data) can be read by toggling a select input to the flip-flop, and reading the data line. Data is written by driving a signal onto the data line and then toggling the select input.

Bit-Flips

Consider what happens if noise were to be induced onto the data line while we were reading its contents. The data value could flip, toggling to the other stable state of the flip-flop. The data value is now corrupt, and will stay that way. These "bit-flips" are not rare theoretical occurrences, but real life events, even in the simplest of designs.

We have all experienced the painful static electricity discharges that occur when touching a large metal object. The discharges that we notice may be several thousand volts; smaller discharges will go unnoticed but can be strong enough to cause bit-flip in unprotected circuits. They may not damage your circuits but they will play havoc with your software!

Bit-flipping of configuration registers can lead to some interesting effects:

- The program counter may suddenly jump to a completely random location
- Unused interrupts can suddenly occur
- I/O pins change from being outputs and inputs, or vice-versa
- Variables can change value

Sudden changes in the program counter tend to be the most common problem. This is because bit-flip is most likely to occur when a RAM cell is being accessed, and the program counter is read and written to every time an instruction executes.

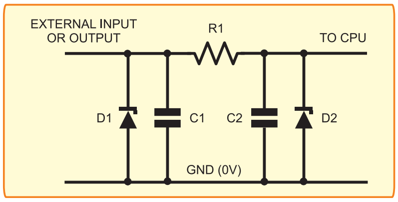

Fig.1. Simple but effective input or output pin protection

Let's first consider some simple hardware design techniques that help reduce corruption caused by electrical noise:

- Place a ground track around the perimeter of your board, connected to signal ground
- Avoid exposing any metal parts to the outside world
- If using an external crystal, the ground connection should go straight to the processor ground pin and nowhere else. Do not use it as a return path for other components
- Place decoupling capacitors close to ICs. One per chip is not unreasonable
- Never leave an input pin unconnected. Always tie it to one of the supply rails, through a low value resistor (say, 470 ohm)
- Unused output pins should be set low and tied to ground through a 470 ohm resistor
- Use low-pass filters on signals that really must go to the outside world

Filter Point

The final point is worth expanding on. It is inevitable that data interfaces and switches will provide a metallic path between the outside and the PCB, and so will bear the brunt of any stray ESD or

other electrical noise. A very effective circuit for protecting each signal line is shown in Fig.1. The resistor, typically around 100 ohms, helps to limit the current while the capacitors, typically around 20pF to 100pF, reduce the slew rate (rise time) of any voltage spike. Additional protection can be provided by one or two Zener diodes, rated around 20% to 30% above the maximum supply voltage (e.g. 6V on a 5V circuit).

For further protection the Zeners can be replaced with transorbs. These devices act like a pair of back-to-back Zener diodes, conducting when their specified voltage limit is exceeded. They can absorb an enormous amount of energy for their size, without permanent damage. They are relatively expensive, however. No matter what you do a good ground path is essential in your circuit.

Testing Effectiveness

Testing the effectiveness of changes and finding the weak areas on a board can be a challenge. Calibrated ESD discharge guns are expensive and require specially constructed metal test benches; not really an option for the hobbyist.

There is, however, a cheap, effective alternative that can produce reasonably repeatable results: the humble piezo gas lighter. Normally used to light gas hobs, when operated in close proximity to your PCB these handheld spark generators are guaranteed to send the microcontroller into a frenzy of random activity. Moving the head of the lighter away from the board until the problems stop will give an indication of the relative susceptibility of the circuit, and where the hot spots are.

The power of the discharge can be increased by opening up the protective metal shield around the central pin and adding a small wire loop, one end connected to the outer shield and the other close to but not touching the pin. Do take care not to come into contact with the discharge, it hurts!

The piezo lighter is an invaluable tool, but do bear in mind that its use may be destructive to your circuit when used in close proximity.

Hiccups

Even with the most pessimistic circuit designs we still have to consider the possibility of a "hiccup" occurring, and try to manage it as gracefully as possible in software. So let's consider some techniques to help improve the software's resilience to erratic microcontroller activity.

Assuming that your code does not fill all the available memory in the device, you should fill all unused program locations with a jump to a reset routine. You cannot simply jump to the beginning of your program; the program stack, which records the return address of each call instruction, will not be reset to zero and your application will crash. On the PIC18F series you can use the new Reset instruction, but on earlier devices you should use the watchdog timer.

The watchdog timer is a timer that slowly increments, and if allowed to overflow will cause a full reset. The software must periodically clear the watchdog timer to avoid this happening. The timer can be set to a timeout of several hundred milliseconds which should provide plenty of flexibility as to where you place the clear instruction. The timer uses its own RC oscillator to remove the risk that an external oscillator might fail – watchdogs are designed to be as reliable as possible! The watchdog is also effective at catching software errors such as infinite loops.

As mentioned earlier, it is possible for peripheral configuration registers to change state, so it is a good idea to re-configure all the hardware features periodically – even unused features of the chip. The I/O port directions should be refreshed, unused interrupt vectors should have code that jumps to the reset routine and so on.

Recording Errors

If you have some spare EEPROM free try to record when unusual events have occurred. This information will help you identify if your hardware is experiencing problems that require additional protection. Try to keep a number of counters for different potential errors. You can remove them later on when you discover that your design is error free (let us know if that happens – you will be the first!)

If you do not have any EEPROM storage available for recording data consider a "fault handler" routine that simply writes a byte out to a port, and stops. You can write the "error code" to the port, and then determine what this code is later with a voltmeter.

Abnormal hardware operation is not the only possible source of problems – In many cases it will be the software that is at fault. One of the best techniques for software error prevention is, amusingly, not writing software in the first place. Re-using code from another project has a number of benefits; you save time by not re-inventing the wheel, and you are providing additional testing of the code under different circumstances. Any errors found in the code can be passed back to the other projects where the code is used, perhaps before the problem is noticed. It's a virtuous circle.

Studies have shown that almost 80% of all coding errors occur in assignments. That is, when we assign a value to a variable. Take this code for example:

bsf Flags1, MEMORY_ERROR_BIT
bcf Flags1, DATA_VALID_BIT

At first glance it looks like nice code. The constants are clearly labelled, and even without comments you probably have some clue as to what is going on. There is, however, a bug in that code. Can you see it? No, of course not!

Had we taken a bit more care with our method of naming constants, we might have come up with the following:

bsf Flags1, FLAGS1_MEMORY_ERROR_BIT
bcf Flags1, FLAGS2_DATA_VALID_BIT

Ah! now we can see the fault. The person who wrote this code thoughtfully placed the name of the variable in which the flag bit is used at the beginning of the constant's name. We can instantly see a typo – the second line of code writes to Flags1 rather than Flags2. Such a simple decision has reduced the likelihood of assignment errors creeping into our code. You might still make the error typing in the code, but you're much more likely to spot the error when re-reading the code. (You do re-read your code, don't you?)

You are free to give variables and constants meaningful names, so make the most of it.

Vital Testing

It's vitally important that you test all of your software. You may not be able to test all permutations of paths through it; in most cases this will be impossible. Testing each instruction in your code at least once should be a minimum goal.

In cases were it is difficult to cause a certain path through the code to execute you can write test code (called a "test harness") that jumps into it. Once you are happy that your code is working you can take out the test code and move on. It's often a good idea to leave in the test code, commented out so you can reuse it later if you make any code changes.

Sometimes it is useful to have a source of random, yet repeatable data. Rather than pressing buttons in a random order, you could consider building into your "test code" a pseudo random number generator function. This can be used to create seemingly random series of numbers that can be "replayed" if necessary.

We will discuss implementing PRBSs in next month's article.

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READOUT

Email: john.becker@wimborne.co.uk

John Becker addresses some of the general points readers have raised. Have you anything interesting to say? Drop us a line!

All letters quoted here have previously been replied to directly.

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★ LETTER OF THE MONTH ★

Solid-State Hammond

Dear EPE

As a tech/keyboardist, I write to you about Thomas Scarborough's *Solid-State Hammond* article (Dec '05). I welcome his work, but we need to clear up a significant historical misunderstanding about it.

Laurens Hammond was an electrical engineer and prolific inventor, but non-musician and tone deaf by his own admission, who invented the organ that carries his name. Its key points are magneto-mechanical tone generation using gearboxes driving "tonewheels" carrying waveshapes, and "drawbars" to allow a totally controlled mixing of musical "partials". The drawbars were inspired but the gears give these organs a unique "temperament" or semitone spacing.

What Mr Scarborough is obviously trying to emulate, however, is a "Leslie" rotating speaker, invented by Don Leslie, also in the 1930s. Leslie tried to interest Hammond in his invention but was rebuffed, and Laurens Hammond personally took an active anti-Leslie stance for over 30 years. Hammond's almost irrational response was, "I never intended for my organs to sound that way", hubris with a tin ear. The credit for rotating speakers and their delightful "crystal shimmer" is entirely Don Leslie's.

Leslie said he never advertised because the word of bad-mouth by the Hammond company sold everything he could manufacture! Hammond agents sold Leslies "under the counter" because customers demanded them, but OEM Leslies were fitted only after CBS bought Hammond and Laurens retired.

Despite this amazing and unfortunate situation, and hence the need for an adaptor kit, the sound of the B3 Hammond-plus-Leslie combination has become the last word for most keyboardists. While many electronic imitators have been devised it is generally agreed that, so far, nothing quite matches the sound of a real rotating Leslie speaker. 1950's Leslies still sell for several times their new price. They also have twin valve amps which produce a very sexy overload "tiger growl", but are diabolical to move and mic up for recording.

The signal is "crossed over" at about 800Hz and fed to two contra-rotating deflector assemblies, a pressure-driven horn and a drum, each fitted with two-speed drives. As the deflectors rotate they produce the same sort of amplitude modulation that this circuit produces, but they also do a lot more.

Two "lighthouse" beams of sound sweep around the venue, moving the apparent source and producing doppler shift. At high speed the treble horn also adds significant doppler shift to produce vibrato, that is frequency/phase modulation as well as tremelo or AM modulation.

But most players use the Leslie running up and down rather than just slow or fast, and this brings in the different inertia of the two deflectors which adds a pleasing sonic complexity. Simulation requires frequency modulation correctly phased to the AM (90 degrees leading). Smooth speed changing with differing, but player controllable, "rotor agility" for highs and lows is also required to simulate the run up and down of which players make so much use.

While Mr Scarborough's design could form the core of a more realistic Leslie simulator by adding different control elements, my own investigations have led me to a VC polyphase function generator driving gross phase shifters, and amplitude modulators around OTAs. It's still a rich area for amateur investigation. Here are a few references:

http://ozvalveamps.elands.com/
http://ozvalveamps.lucidtone.com/
www.theatreorgans.com/hammond/ faq/mystery/mystery.html
www.mitatechs.com/leslierumors.html
http://users.chariot.net.au/~dna/hammond.html
www.137.com/hammond/leslie.html

As well as Deep Purple, Procol Harem, Booker T and the MGs, Santana.

Roly Roper, Ivanhoe, Melbourne, Australia

Thank you Roly, and from Thomas, who found your comments informative.

Avast! Anti-Virus Awarded

Further to last month's *Readout* Avast! Anti-Virus Nightmare letters, Alan Winstanley tells me that Avast! has been awarded.

The full text can be read at **www.avast.com/eng/avast_wins_sc_award.html**, but the gist is that ALWIL Software (Avast's originator) has won the prestigious SC Reader's Choice Awards for the best anti-virus for the USA section of the award event.

ALWIL Software's Avast! product was up against nominated industry leaders in the category, including: McAfee Inc – McAfee VirusScan Enterprise 8.0i; Symantec Corporation – Symantec AntiVirus Corporate Edition 10.0 and Aladdin Knowledge Systems – Aladdin eSafe. The annual awards are one of the most important awards run each year, with over 300 companies competing with over 1300 products and services. ALWIL Software has produced antivirus products since 1988.

Scart Leads and Cable Detectors

Dear EPE

Reading Colin Rimmington's letter in February *Readout*:

I have also found DIY store supplied cable and live wire detectors very disappointing. Possibly part of the problem is modern wallpaper adhesives, that maintain a humid layer? With one exception I haven't had anything I would rely on to find a safe drilling location. The honourable exception is the cable and live wire detector from Tchibo; TCM brand available from the shops from time to time and on line at **www.tchibo.co.uk**, the "Electric Multi-Tester" at £5, find it under the "Check It" panel on the home page. No connection with Tchibo other than a satisfied customer!

As a general rule before doing any drilling you need to have a good idea where the utilities run, before relying on a detector.

Secondly, can anyone suggest the maximum length I could make a Scart lead for a not very demanding application, video and mono audio in one direction only? Overall cable diameter needs to be as small as possible, so conventional cabling is probably out.

Peter Gee, via email

Thanks Peter. Can anyone help with Peter's query?

Yet More C Feedback

We've received more responses to the letters from David Parkins and Dr Jim Arlow in the Jan '06 issue. As previously said here, we are taking active steps to bring you a general feature on "Using C for PICs" later this year. Here is a further selection of the feedback:

I received the Jan '06 issue and performed my monthly ritual of glancing through all the pages, I read with interest about the considerations of using AVR microcontrollers and C language in *EPE*. For this, I would like to give my opinion.

For many years, I've developed many applications with microcontrollers and also taught about them in my country of origin, Mexico. In all these years I read two popular (you can guess which) magazines from Gernsback publications. Unfortunately I witnessed first the merging of both of them and later I saw how they disappeared.

In the last years many articles using microcontrollers of different brands (including PICs) were published, but it was difficult to conclude the project if that particular programming platform was not the one of choice, and porting from one platform to another could become very difficult without the necessary knowledge. Also, the articles described in detail the hardware, but most of the times the routines just had a brief description and the details had to be acquired from the program itself, not an easy task especially if it is not well commented. When this magazine finally disappeared, it left me with a sense of emptiness for some years that only has been filled when I came to England for studying my PhD and discovered your magazine two years ago.

Increasingly Difficult

About the programming language, an important point has been established in your appended reply, "All at C – As Quickly As Possible!". When we program computers, all the hardware is hidden to the programmer (if he or she is not programming an embedded application), and this allows higher levels of abstraction. In the microcontroller world, we place our micros all the time in an electronic circuit which we also need to understand, and thus it is important to know exactly what our program is doing. Get one bit wrong and it will not work.

The level of abstraction given by the C language could increase the difficulty of finding a problem when our application doesn't perform as expected, especially when we don't have the necessary experience given by programming with assembly language. Normally, I would expect from my students that they will know exactly what happens with the Carry flag when they perform a rotation for turning on all those LEDs, and simple things like this could be hidden in C.

In some other real-time routines, I will only use assembly language. For this reason, I think that in this world of microcontrollers, both the knowledge of the programming and the hardware are fundamental, as opposed to the PC world. If you turn on and off a transistor too fast (in C or assembly) it could not work (learned the hard way). Thus, the first correct step is to learn assembly language, and it is still possible to perform a modular programming, increasing the level of abstraction when you use your own well-proved and understood routines.

Many years ago I developed my own routines in assembly for using an LCD (for a Z80, the first micro I learned), for doing that I had to understand the hardware and programming issues for this component, but once developed and improved (yes, they didn't work at the first time), I could just call them and concentrate on other aspects of the application, and re-use them in some others.

The size of the memory should also be considered, probably even more if C language is used, because this is one of the criteria we use for selecting the model of the micro, but probably this is more of a concern depending on the complexity of the application and its intended use. If my program is going to run in a hundred-thousand production (like the meters used in taxis back in Mexico) I don't want to waste memory that will obligate me to go to a bigger and more expensive model of the micro that will reduce my profit.

My Suggestion Is . . .

But certainly there are situations in which C language would represent an advantage. For example, in a PID controller (which I am working with now for the Micromouse contest), where some arithmetic operations need to be performed. I know it is difficult to do this in assembly (because I've done it), so I started to play with C.

By the way, a tip for those readers who would like to experiment with C, I recommend checking the UK eBay page and make a search for PIC microcontrollers, among another things you will find (at the time of sending this email, but it is offered most of the time) an auction for the Boost C Compiler, which could be more affordable than if you buy it directly with the provider (actually, the eBay option is given by one of them, everything is legal). The amount of examples provided with the compiler and the web page of the creators (I don't have any connections with them, I just like their compiler) represent a good starting point.

So, my suggestions for the magazine are to keep the applications in assembly (even with all those years I keep learning from them), but also consider using C for the more experienced readers, definitely I would like to see a tutorial in the *Pic N' Mix* column. But please-please-please, keep using only PICs.

I know that many AVR programmers will not agree, so I recommend you to do some statistics (polls), maybe through your (magnificent) web site and see if the number of people interested in AVRs are enough. If it is like this, then you could consider placing on the web site the programming issues and circuits for AVRs for some of the articles in the magazine, maybe not necessarily the ones in the current one (at least in the beginning), there are plenty of excellent applications in past numbers that I am sure many AVR programmers would like to see.

Probably like this, you could extend your audience and satisfy most of the people (a difficult task), and this could represent a business opportunity for some avid AVR programmers. But be aware that also the Freescale (previous Motorola) programmers could be tipped off and will start complaining!

Next year will be my last one in your country, and one of the things going back with me will be my subscription to your (excellent) magazine. I congratulate you on the new presentation, the schematics almost jump to me with the new colours!

Alex Butron,
University of East Anglia

I am sure that what Dr Arlow writes over the desirability of using C rather than assembler is all true. But I don't think it's the full story. I want to put forward my own beliefs on the topic. By way of preface I should assert I used C for a number of years.

1. I like writing in assembler; to me it is a kind of poetry, and I get a kick out of it when it rhymes (so to speak).

2. As a former electrical engineer, now hobbyist, I can now afford to do things the way I like doing them, even if they are less efficient than other methods. By analogy, my main hobby is model railways, and I could go out and buy more ready-made stuff than I actually do, but don't because I want to do my own thing. At my age, I am a firm believer in exercising those "little grey cells".

3. As I write an assembler program I know exactly where my arrays go in data memory. Would a C compiler tell me that I was overrunning existing data memory? The Visual C++ compiler I use for C programs on my PC does not. Likewise, would C tell me at compile time if I might overrun the PIC stack at run time?

4. How would I do interrupts, such as those used with the I^2C hardware in the 16F877 and 18F452? Having spent much effort in understanding how I^2C works, and making it work, I would be reluctant to go through the same thing with C.

5. Much of what I do involves timing loops, typically loops within loops. How can I be sure that the C compiler will give me the timing and order of events I plan on?

No doubt Dr Arlow could assert that all my objections are without foundation. If so, it would boil down to, stubborn cuss that I am, that I will do things the way I like!

John Waller, USA

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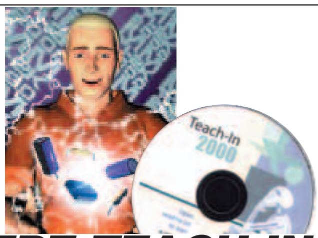

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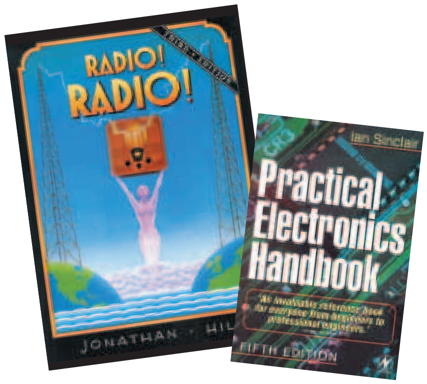

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During the Second World War, Alan Blumlein was deeply engaged in the very secret work of radar development and contributed enormously to the system eventually to become 'H25' – blind-bombing radar. Tragically, during an experimental H2S flight in June 1942, the Halifax bomber in which Blumlein and several colleagues were flying, crashed and all aboard were killed. He was just days short of his thirty-ninth birthday.

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Everyday Practical Electronics, periodicals pending, ISSN 0262 3617 is published twelve times a year by Wimborne Publishing Ltd., USA agent USACAN at 1320 Route 9, Champlain, NY 12919. Subscription price in US $60(US) per annum. Periodicals postage paid at Champlain NY and at additional mailing offices. POSTMASTER: Send USA and Canada address changes to Everyday Practical Electronics, c/o Express Mag., PO Box 2769, Plattsburgh, NY, USA 12901-0239.

Published on approximately the second Thursday of each month by Wimborne Publishing Ltd., 408 Wimborne Road East, Ferndown, Dorset BH22 9ND. Printed in England by Apple Web Offset Ltd., Warrington, WA1 4RW. Distributed by Seymour, 86 Newman St., London W1T 3EX. **Subscriptions** INLAND: £17.50 (6 months); £33 (12 months); £61 (2 years). OVERSEAS: Standard air service, £20.50 (6 months); £39 (12 months); £73 (2 years). Express airmail, £29.50 (6 months); £57 (12 months); £109 (2 years). Payments payable to "Everyday Practical Electronics", Subs Dept, Wimborne Publishing Ltd. **Email:** subs@epemag.wimborne.co.uk. EVERYDAY PRACTICAL ELECTRONICS is sold subject to the following conditions, namely that it shall not, without the written consent of the Publishers first having been given, be lent, resold, hired out or otherwise disposed of by way of Trade at more than the recommended selling price shown on the cover, and that it shall not be lent, resold, hired out or otherwise disposed of in a mutilated condition or in any unauthorised cover by way of Trade or affixed to or as part of any publication or advertising, literary or pictorial matter whatsoever.